

Evaluating the Economics of Construction and Demolition
Waste Minimisation and Zero Waste in the New Zealand
Construction Industry

Van Tran

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Waste Minimisation and Zero Waste in the New Zealand
Construction Industry

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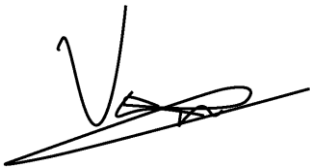
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Faculty of Design and Creative Technologies

Auckland University of Technology

Attestation of Authorship

I, Van Dai Tran, hereby declare that this thesis is my own work and that, to the best of my knowledge, does not contain any materials previously or currently published or written by another person - nor does it contain any material which to a substantial extent has been accepted for the award of any other degrees at any other universities.

A handwritten signature in black ink, appearing to be 'Van Dai Tran', written over a horizontal line.

Van Tran.

ABSTRACT

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Currently, up to 50% of construction and demolition (C&D) waste is disposed of in landfills contributing to significant environmental, social and economic costs to New Zealand. However, current understanding of C&D costs is poor both internationally and within New Zealand. This thesis addresses this deficit by developing a framework to evaluate the economics of C&D waste minimisation. An understanding gained from this research could help New Zealand develop appropriate strategies to address C&D waste issues.

As the research problem is complex and wide-ranging, this study used a mixed-method approach. Semi-structured elite interviews with highly experienced construction personnel were used to identify factors affecting a C&D waste minimisation strategy. This also established the context of the economic evaluation framework. Economic modelling was subsequently employed to develop the economic evaluation framework. The framework was then applied on two case studies: 1) a development of a large education facility and 2) a refurbishment of a commercial office space.

The study found that:

1. a C&D waste landfill/cleanfill charge of \$150 per tonne can a) deter construction from disposing of waste; and b) force construction to rethink waste disposal
2. C&D waste minimisation can offer clients benefits including tangible returns (i.e. cost savings) and intangible potentials (i.e. increased reputation)
3. there are costs of implementing C&D waste minimisation - but benefits gained can outweigh such costs; and
4. the optimal rate of reduction for C&D waste in the non-residential projects studied was 71% - 78%

ABSTRACT

Overall, this research has made a contribution to knowledge through the development of a robust economic evaluation framework. Moreover, the study has also provided an impetus for future work in C&D waste minimisation economics in New Zealand.

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CHAPTER 1 - INTRODUCTION

CHAPTER 1 – INTRODUCTION

The construction industry has an important role in the national economy of countries around the world (Shakantu, 2005). Construction contributes significantly to the competitiveness and prosperity of the overall economy both directly and indirectly (Lawson, 2013). In direct terms, construction contributes between 5% and 7% of any nation's Gross Domestic Product (GDP) and is one of the largest employers in any economy (Australian Bureau of Statistics, 2010; Building Performance, 2015; UK Government, 2015). The indirect influences of construction on the economy are even more pronounced, with the industry representing around 50% of Gross Fixed Capital Formation in most countries (Wibowo, 2003; PwC, 2011).

However, construction is well-known for its ineffective use of resources, leading to significant wastages (LePatner, 2008; Landin & Oberg, 2014). Recently significant efforts have been invested in tackling the waste problem created in, and by, the industry. The study reported in this thesis focuses on one aspect of these efforts: the economics of construction and demolition (C&D) waste minimisation. By understanding this aspect, it is anticipated that appropriate strategies can be made to improve waste minimisation in the New Zealand construction industry.

1.1. Defining C&D Waste

C&D waste is a term collectively given to all waste generated by the construction industry. Currently there is no single definition of C&D waste (Kumara, 2009). For example, the Environment Protection Authority (EPA) in South Australia has two definitions of C&D waste: one for inert stream and one for mixed stream (EPA, 2009).

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In New Zealand, C&D waste is not specifically defined in the Waste Minimisation Act 2008; rather it is included in the Ministry for the Environment's (MfE) general definition of waste – although a list of C&D waste streams is provided by the MfE (MfE, 2008; MfE, 2017). This lack of C&D waste in New Zealand means that C&D waste minimisation practices are not uniformly adopted between locations and authorities, leading to variations in C&D waste classification and management strategies. In turns, this means efforts to address C&D waste are different between locations which further exacerbates the problems with C&D waste in construction.

This lack of a uniform C&D waste definition means that there is an urgent need to define C&D waste in this study. The definition of C&D waste in this research should be broad enough to cover the essence of C&D waste in construction context; but it should be limited within the scope of the study.

1.1.1. Working Definition of Waste

Although New Zealand has a definition of 'waste' in the Waste Minimisation Act 2008 (MfE, 2008), the researcher feels that the MfE's waste definition is too broad. Given the research problem being investigated is wide-ranging, there is a need to provide necessary focuses in this research to ensure the research problem can be addressed within the allocated 3-year timeframe.

Therefore, a conscious decision was made in this research to adopt the definition of 'waste' offered by the United Nations Statistics Division (UNStats) due to its specificity. In this study, 'waste' is defined as 'materials that are not prime products for which the generator has no further use in terms of purposes of production, transformation or consumption, and of which the generator wants to dispose' (UNStats, 2015).

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As shown in this definition, the main focus of current waste management paradigm rests on the management of physical waste. This focus has been the main platform upon which waste management strategies are formulated and executed (see, for example, Hyder Consulting et al, 2011 or Marshall & Farahbakhsh, 2013). Although this line of thought has allowed for successful implementations of many waste management/waste minimisation strategies (e.g. Allen et al, 2012), it is becoming outdated (Seadon, 2010). Current thinking around waste minimisation includes aspects of the 'lean' concept. In this new paradigm, wastage includes non-quantifiable factors such as time, delays, defects and under-utilisation of skills (Rogers Builders, 2010; Mortensen Construction, 2013; Aitken, 2014).

1.1.2. Working Definition of C&D Waste

In the construction context, this new line of thinking of waste is particularly applicable. C&D waste consists of two components: physical waste and process waste. The physical component of C&D waste is generated during the construction and demolition processes. Physical waste includes, but is not limited to, bricks, glass, plastics, concrete, timber, asphalt, gypsum and metals. As the physical C&D waste consists of many chemicals as a result of industrial processes, when discarded to the environment, these waste streams can have significant negative effects to the surrounding environments and on human health (Coudert et al 2013; Kijjanapanich et al, 2013).

On the other hand, process waste is mainly generated by the industry's sub-optimal operations. Process waste may include, but is not limited to, time, delays and skills. Although both physical waste and process waste affect the bottom lines of construction companies, it is the latter that can have the most significant effects on construction, as it

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undermines the ability of the industry to deliver stated outcomes. Further, process waste can cost companies and industry significantly in term of productivity, which in turns lowers the industry's competitiveness. Process waste has been extensively studied in the field of Lean Construction (Howell, 1999). Although the consideration of process waste is required to provide a complete picture around C&D waste in construction, the fact that it lies outside of the scope of this study means that C&D waste does not cover this aspect in its definition.

Therefore, in this research C&D waste is defined as 'materials which arise from the construction and/or demolition of buildings, structures or likewise, for which the generator has no further use for the purpose of continued production and/or consumption, and of which the generator wants to dispose' (UNStats, 2015).

1.2. Problems with C&D Waste

C&D waste is a significant problem world-wide due to it being generated in large quantities throughout the life of a structure (Conlin, 2012; Hassan et al, 2012). C&D waste is present in all stages: from construction to maintenance and renovation, and finally though to demolition of the building or structure. The problem with C&D waste is not new. In Brazil, Soibelman (1993) monitored the waste of seven materials in five building sites and found values ranging from 5.06% to 11.62% in terms of cost. In Norway, Sjøholt (1998) estimated that the costs due to nonconformity, errors, alterations and wastage during the building process were around 10% of the total building cost. It has been consistently shown in the literature that C&D waste represents between 10% and 36% of all landfill waste worldwide (Kartam et al, 2004; Tam & Tam,

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2006; Tam, 2007; Yuan & Shen 2011; Hu, 2011; Hassan et al, 2012). The large volumes of C&D waste can have significant environmental impacts due to leachate of hazardous materials from chemical and industrial treatments (Wang et al, 2010; Coudert et al 2013; Kijjanapanich et al, 2013).

It has been argued that a significant amount of C&D waste can be diverted by implementing 'design-out-waste' concept (Chong et al, 2009; WRAP, 2011, 2012). However, design-out-waste is not widely practised due mainly to a (false) perception of its high cost of implementation (Osmani, et al, 2008). Perhaps this is the reason the problem with waste generation in construction, and particularly C&D waste, continues to persist.

Comparatively the situation in New Zealand is by turn much better and worse than elsewhere. Latest figures from the Ministry for the Environment showed that nationally C&D waste comprises 50% of all waste generated in New Zealand (MfE, 2013). An area by area comparison showed construction in the Auckland region generated 35% of the whole region's waste output. Further, publicly available information shows that performance figures for waste minimisation have not markedly improved between 1997 and present day, with The Ministry for the Environment website continues to cite C&D waste arising as constituting circa 20% of all landfill and 80% of all cleanfill deposits, just as they did in 1997 (MfE website, 2013). At the same time, the sizes of available landfill and cleanfill sites in New Zealand have been significantly reduced due to C&D waste being continually dumped into landfills or cleanfills (Kazor and Koppel, 2007). For example, in the case of plasterboard-type products there is only one licensed cleanfill disposal location in the Auckland region (the Envirofert facility at Tuakau). In turns, the reduction of available landfills and cleanfills makes the problem with C&D waste even

more acute. It has been argued that most C&D waste in New Zealand is disposed unnecessarily due to sub-optimal processes (Level, 2015). The result is at least 50% of C&D waste currently in landfills or cleanfills could be diverted. This shows there is a need for immediate attention from all stakeholders in New Zealand, both inside and outside of the construction industry, to address C&D waste.

1.3. Estimates of potential gains from minimising C&D waste internationally

The cost of C&D waste can be broadly divided into three categories: Environmental Cost, Social Cost and Economic Cost – but most attention is paid exclusively to the economic component (Peng, 2010; Level, 2015).

1.3.1. Environmental Cost of C&D Waste

The environmental cost of C&D waste is represented by two areas: resource depletion and pollution.

1.3.1.1. *Resource Depletion*

As shown in Section 1.2, construction's ineffective use of materials in its production processes represents a major problem. On the one hand, the industry continues to require a significant amount of natural and virgin materials (Fadiya et al, 2014). Available statistics shows that globally construction requires up to 50% of the world's energy, 50% of the world's water uses and between 60% - 90% of the world's timber products (Willmott Dixon Co., 2010).

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On the other hand, the industry continues to generate a significant amount of C&D waste – sometimes up to 50% of all landfill waste (Kievan, 2013; MfE, 2013). Further, it has been documented that construction has contributed to the significant air pollution in cities (23%) and drinking water pollution (40%) (Willmott Dixon Co., 2010). All this represents in a severe depletion of natural resources.

It can be seen in the above argument that in the long term this ‘mine-build-discard’ mindset is not sustainable, given the world’s limited natural resources (Seadon, 2010). Therefore, there is a need for construction to take a broader view of its actions and reconsider its responsibilities, especially those around waste minimisation.

1.3.1.2. *Pollution*

Pollution caused by construction includes air, noise and soil pollution.

Air pollution includes dust generated during demolition and fumes from exhaust and other combustible emissions of transport vehicles. Air pollution such as dust can cause significant nuisance to the local communities if not managed properly. This type of pollution can have significant effects on the surrounding communities during the generation and disposal of C&D waste (Fayad & Bekhazi, 2009).

Noise pollution is mainly caused by construction and demolition activities. This type of pollution can cause significant nuisance communities. Further, the vibration from construction and/or demolition activities can also cause damages to surrounding structures and buildings.

On the other hand, soil pollution is caused by leachate of heavy metals or chemicals over time (Wang, 2010). Construction materials are often treated with chemicals to prolong their working lives. When treated materials are disposed of in landfills, such

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chemicals are released into the environment as the materials breakdown, causing soil and water pollution (van der Sloot et al, 1996). The effects of soil pollutions are significant because they can affect the land and underground water tables which cities rely on to serve their citizens.

Greenhouse gas (GHG) emission in the context of C&D waste is mainly generated during the transportation and processing of C&D waste. As C&D waste is often bulky, large machinery are required to transport and process it, resulting in a large amount of carbon dioxide (CO₂) being released into the atmosphere. It has been argued that the construction industry generates an equivalent of 50% of all global greenhouse gases (Willmott Dixon Co., 2010). Pollution and GHG emission can cost the country and the planet significantly. These costs can be calculated in terms of health and wellbeing of citizens. They can also be calculated in terms of the efforts and money spent on mitigating the effects of such pollution. Further, the costs can be in terms of lost opportunities such as the limited opportunities to reuse landfill sites due to potential health hazards (Level, 2015).

However, most current C&D waste and C&D waste minimisation studies only briefly mention the environmental issues related to pollution and GHG (see, for example: Fayad et al, 2009; Fadiya et al, 2014; Wang et al, 2014; Kucukvar et al, 2015). A small number of studies explore GHG in C&D waste minimisation. But they used estimates and assumptions to model the effects of pollution in C&D waste minimisation (see, for example: Coelho & de Brito, 2012; Kucukvar et al, 2015). In the researcher's opinion, this is an area which further research effort is needed.

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Overall, as can be seen in the discussions of environmental components above, C&D waste can have significant effects on the surrounding environments. Therefore, there is an urgent need for the construction industry to manage and minimise its C&D waste output to reduce these environmental impacts.

Further, as the above environmental impacts can be severe and may have long term impacts, their costs may be borne by the society in general. The following section discusses the social cost of C&D waste in detail to provide an understanding of this topic.

1.3.2. Social Cost of C&D Waste

Social cost is the costs to the communities and to construction companies in dealing with the effects of C&D waste pollution. Social cost of C&D waste can be measured directly or indirectly.

Direct social costs include reparation costs to damaged properties or costs to address communities' concerns. Reparation costs arise from the need to address damages to structures and buildings caused by noise and vibration pollution. These costs are often borne by construction companies. However, the fact that local communities suffer such damages and discomfort before reparatory work is carried out means that the social cost associated with this pollution is also significant. Community-related costs arise from the need to address communities' concerns regarding projects or critical activities in such projects. For example, communities may be affected by the increase in traffic during construction and/or demolition processes. Not only does the increased traffic cause delays and congestions to local networks, it also increases the risk for public and

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workers' safety, especially during peak hours or at schools' opening and closing times. For these reasons, the social cost to construction is significant, including oppositions to a project by communities.

On the other hand, indirect social cost includes the costs borne by the public health systems in treating accidents or diseases arisen from C&D waste pollution. For example, it has been shown that high levels of air pollutants can cause sickness and other respiratory problems to the people working at and/or living around the construction or demolition sites (Fayad & Bekhazi, 2009). The health cost associated with this type of pollution is often borne by society.

To reduce the social cost (both in direct and indirect terms) means that there is a need to minimise C&D waste. And to ensure a waste minimisation strategy is sustainable, there is a need to understand the economics of such a strategy. The following section will discuss the economic cost of C&D waste in detail.

1.3.3. Economic Cost of C&D Waste

Arguably, the economic cost of C&D waste has a direct relationship to both environmental and social cost of C&D waste.

From the environmental perspective, as the amount of C&D waste being disposed of by the construction industry continues to grow, there is an increased need for additional landfill sites or cleanfill sites to help manage C&D waste. There are costs associated with these additional investments in infrastructure. And although the costs of such investments may be high, the investors may also require high return rates to justify their investments. The returns for the investors are in forms of waste disposal fees or landfill charges. As landfill charges grow, so do the costs of C&D waste disposal. In other

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words, high landfill charges make it expensive to dispose of C&D waste. In many economic situations, construction companies would pass these costs onto the consumers to compensate for their high cost of waste disposal. Given that the amount of C&D waste keeps growing (not declining), the end consumers end up paying more for materials and wastages, labour to process C&D waste, and transportation of C&D waste. It is therefore in the consumers' best interest to demand construction companies to cut down unnecessary costs. And it can be done through minimising the amount of C&D waste produced in projects. By having a waste minimisation strategy, the client can ensure they save on materials as well as on waste disposal charges.

From a socio-environmental perspective, as the social cost of C&D waste grows, it becomes a substantial burden for society (Storey et al, 2003; Myers, 2005; Ding, 2008; MfE, 2010). Although some parts of the social cost is borne by construction companies (see Section 1.3.2), a majority of the social cost of C&D waste is borne by the public (Fayad & Bekhazi, 2009; Willmott Dixon Co., 2010). For instance, as the amount of C&D waste keeps growing, so does the amount of health problems associated with it. The growing C&D waste-related health problems will likely stretch the (already-stretched) public health systems worldwide further.

C&D waste is a major issue faced by both the society and the construction industry. Given the problem with C&D waste is serious and has been around for a long time, there is an urgent need for construction to address C&D waste.

As money is an important consideration in construction, there is an immediate need to investigate the economics of C&D waste reduction strategies in the New Zealand construction industry. This is the rationale for the study reported in this thesis.

1.4. Other dimensions affecting C&D waste minimisation

1.4.1. Political dimension of C&D waste minimisation

The pressure for reducing C&D waste in construction comes from various levels: local, national and international (Snow, 2001). One particularly significant aspect in recent years has been the introduction of much legislation and many directives worldwide aiming to improve industrial and social sustainability (Langfield, 2011; Metro Vancouver, 2011; Adams et al, 2011; Seattle Council, 2013). In New Zealand, the Waste Management Act was introduced in 2008 to change the status quo of waste in construction. The principle mechanism of the Waste Management Act (2008) was to provide funding for waste minimisation programmes, enable product stewardship schemes for construction materials and reduce the environmental harms caused by those materials. This can be achieved by the imposition of a levy on all waste sent to landfills. The levy creates an economic imperative to reduce total amounts of waste arising from construction sites and introduce waste minimisation. Specifically, each tonne of waste removed from sites and deposited into landfill or cleanfill would result in \$10 levy. The Waste Management Act (2008) was also intended to force people to think about how they dispose of materials more broadly. It has been reported that the overall effects of the Act to date has been positive in the New Zealand context (MfE, 2009; MfE, 2012).

However, compared to other waste minimisation programmes worldwide such as the Sustainability Advantage programme in New South Wales, perhaps New Zealand can do more to encourage C&D waste minimisation. Information about the Sustainable

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Advantage programme can be found on the Environmental New South Wales' website (Environmental New South Wales, 2014).

It has been suggested by overseas authors that maybe the reason for the slow adoption of C&D waste minimisation is due to a lack of necessary supports and interventions by authorities (Jaillon et al, 2009; Hu, 2011). Interventions include 'pull' factors such as incentives and subsidies as well as 'push' factors such as industry-focused legislations and/or industry performance standards. It has been shown that a combination of regulation and economic incentives is effective in reducing C&D waste (Yuan et al, 2011). Similar, Poon et al (2001) and Poon et al (2004) showed that regulations and economics are key factors in influencing and altering behaviours of operatives towards C&D waste generation. Yu et al (2013) showed that C&D-specific waste levy charges can have significant effects on construction's behaviours regarding C&D waste. It has been reported that after 3 years of implementing the Construction Waste Disposal Charging Scheme (2006–2008), Hong Kong managed to significantly reduce solid construction waste (Yu et al, 2013). However, it has been noted that such successful C&D waste reduction scheme is only sustainable if appropriate efforts are made to improve the industry's behaviours towards, and practices in, C&D waste minimisation (Yu et al, 2013).

This observation is valid because top down approaches in waste minimisation (i.e. one driven by policies and regulations) can only drive the agenda so far, there is a need for a bottom-up approach from the industry itself to have a truly lasting and sustainable waste minimisation programme.

1.4.2. Technological dimension of C&D waste minimisation

To date, many authors have relied on technology to minimise C&D waste. For instance, Huang et al (2002) used mechanical sorting techniques to recycle construction waste. This is an interesting study because this type of study is not common in construction. But the novelty of this approach is already available in other sectors such as the mining sector (<http://www.crcore.org.au/coarse-liberation-circuits.html> and <http://www.crcore.org.au/7-news/general-news/110-news-archive> - section 'MineSense joins CRC ORE', 2013).

Similarly, Li et al (2005) utilised mapping technologies such as GPS and GIS used to track and manage onsite C&D waste. Li et al (2005)'s approach was found to be effective in tracking and managing materials and waste. Moreover, compared to the standard approach, greater efficiency and productivity could be gained through this system (Li et al, 2005). Approaches like Li et al (2005)'s has gained popularity in recent times, with increasing number of New Zealand firms employing them to study materials flows (e.g. Aurecon).

Techno-centric approaches have been found to be helpful in the management of C&D materials and waste. However, techno-centric approaches can be costly, as specialist equipment can be expensive and may not be applicable to every project. Besides, there is little evidence that such high-tech approaches are more effective than other waste minimisation techniques. As a result, further research effort is required in this area to help construction understand the role and potentials of techno-centric approaches in the management of C&D waste. This understanding will in turns allow construction to formulate appropriate strategies to manage its C&D waste outputs.

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Although it is technically feasible to recycle most construction materials, the type and amount of material to be salvaged is often highly dependent on its value (Tam & Tam, 2006; Tam, 2010; Lu & Yuan, 2011). This means C&D waste minimisation depends on both construction's technical capabilities as well as levels of commitment of the stakeholders within the industry. This argument shows the importance of economic considerations in C&D waste minimisation. Given monetary returns to shareholder are the key driver in construction, there is a need to assess the economics of waste minimisation strategies so that potential values of C&D waste minimisation can be understood and implemented (Peng et al, 2010). In turns, this understanding of can add significant values to the operations of construction companies and ensure the long-term sustainability of the industry.

1.5. Problem Statement, Research Aim and Research Question

1.5.1. Problem Statement

Currently there is a lack of tools and methods for the evaluation of economics of C&D waste minimisation in New Zealand. This is perhaps since C&D waste minimisation is a relatively new field of research in New Zealand, with very few publications in New Zealand focusing on this area (e.g. Storey, 2003; Brown & Allcock, 2008; Letendre, 2013; Berry, 2014). As a new field of study, there are research areas that need to be addressed and used as the basis for further progresses. One such area in New Zealand is in economic evaluation of C&D waste minimisation.

Worldwide, there are several studies focusing on the economics of C&D waste management/minimisation (see, for example: Yahya & Boussabaine, 2006; Begum et

al, 2006; Tam & Tam, 2008; Jain, 2012; Fadiya et al, 2014; Marzouk & Azab, 2014; Dajadian & Koch, 2014; Abdelhamid, 2014). In New Zealand, currently there is only one publication that explores this area (Covec, 2007).

The lack of economic evaluation frameworks appropriate, and applicable, to New Zealand means that construction stakeholders are not well-informed of the values of waste minimisation. This lack of understanding may in turns have detrimental effects on efforts to address C&D waste problems by the governments and the industry.

To this end, there is an urgent need to evaluate the economics of C&D waste minimisation and C&D zero waste in the context of New Zealand construction.

1.5.2. Research Aim and Objectives

The nature of the current problem means that the aim of this research is to evaluate the economics of a zero-waste strategy in the New Zealand context and to identify the most economically optimal C&D waste minimisation strategy in New Zealand construction projects.

Because of the research aim above, a number of research objectives have been established. These research objectives divide the research aim into manageable components; but together, they help address the research aim effectively.

1. Objective 1: to identify factors that may have significant effects on C&D waste minimisation in New Zealand construction
2. Objective 2: to identify actions needed to encourage the uptake of C&D waste minimisation in New Zealand construction

3. Objective 3: to formulate a framework to evaluate the economics of C&D waste management strategies available to New Zealand construction

By addressing these research objectives, it is anticipated that the study provides a platform for future investigations in C&D waste minimisation in construction.

1.5.3. Research Question

A few research questions have been formed to help address the above research objectives. Research questions in this study are:

1. What are the factors that can significantly affect waste minimisation strategies in New Zealand construction?
2. What techniques are appropriate for estimating costs of a C&D waste minimisation strategy in New Zealand?
3. What techniques are appropriate for valuing benefits of a C&D waste minimisation strategy in New Zealand?
4. What is the basis for choosing the optimal waste minimisation strategy for a project?

These research questions seek to answer each research objective in the following order:

Table 1: Relationship between Research Objectives and Research Questions

RESEARCH OBJECTIVE	RESEARCH QUESTION
1	Research Question 1
2	Research Question 1
3	Research Questions 2, 3, 4

1.6. Thesis Contribution and Overview

Although C&D waste minimisation has been studied internationally, its economics has not been investigated in the New Zealand construction context. This study aims to develop an economic framework that is applicable to the evaluation of C&D waste management strategies in New Zealand. This framework differs to other evaluation methods in that it uses a combination of standard economic evaluation techniques such as Economic Impact Analysis, Benefit-Cost Analysis and Cost Effectiveness Analysis to help convey messages in a clear and concise manner.

With its focus on the investigation of economics of C&D management, this thesis can make significant contributions to an overall understanding of C&D waste management in the context of New Zealand construction. The thesis is organised as follows:

Chapter 2 reviews relevant literature pertaining to C&D waste management and C&D waste minimisation. The aim of this chapter is to develop a good understanding of issues around C&D waste minimisation and to identify existing knowledge gaps in order to establish research strategies to address them.

Chapter 3 reviews economic evaluation techniques. This chapter aims to provide a good understanding of economic evaluation tools that are available for this research. The chapter concludes with a list of appropriate economic evaluation methods for this research.

Chapter 4 discusses the methodology adopted for this research and reasoning for the choice of the research instrument. Ontologically, the study followed the Parmenidean worldview, given its focus on developing an economic evaluation framework.

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Epistemologically, a mixed-paradigm was chosen as to address both qualitative and quantitative aspects of the research. Subsequently the chapter shows suitable research methods for this study are: semi-structured elite interviewing, modelling research and case study.

Chapter 5 outlines the theoretical construct of the proposed economic evaluation framework and provides descriptions of its applications.

Chapter 6 applies the proposed economic evaluation framework to a new construction project. This Chapter focuses on evaluating the economics of minimising a range of C&D waste materials, including asbestos-contaminated materials, concrete, scrap metals, timber, plasterboard, steel, cardboard, glass, hardfill materials, plastic, polyester materials and other general waste.

Chapter 7 further tests the application of the proposed economic evaluation framework in a refurbishment project. This Chapter focuses on the brick material. And the framework is used to evaluate the economics of waste minimisation strategies for brick waste.

Chapter 8 discusses key findings from this study. The chapter describes how each research objective is achieved. This chapter also describes the key strengths and limitations of the study and suggests opportunities for future research.

Finally, conclusions are set at Chapter 9.

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2.1. Sources of C&D Waste

There are many factors that can have significant effects on the generation of C&D waste. However, two main factors that contribute significantly to the generation of wastages in construction are the industry's fragmented nature and current practices being carried out in the industry.

2.1.1. Industry Fragmentation as a Source of Waste

A significant factor in waste generation is perhaps the fragmented nature of the construction industry. The construction industry is made up by a large number of small-to-medium sized companies. In New Zealand, there are a total of 51,178 companies operating in the construction sector as of 2014 (Statistics New Zealand, 2015). Of this total, 24% (or 12,285 companies) are proprietary (Statistics New Zealand, 2015).

Construction's fragmentation is not new and it has both positive and negative implications to construction (Egan, 1998). On the one hand, the fragmentation allows the industry to be flexible to deal with the variable workloads caused by economic cycles (Egan, 1998). On the other, due to this fragmentation each trade tends to focus on their area of expertise and thus limiting the continuous collaborations between partners (Barawas et al, 2013). Because of this fragmentation, the views on C&D waste between construction groups differ significantly. For instance, waste minimisation is not highly ranked in the design process by architects (Osmani et al, 2008); however civil engineers felt that more could be done at the design phase to minimise waste (Chong et al, 2009).

2.1.2. Wastages in Construction Practice

It has been reported that over-specification of materials is a main reason for wastages in construction (Sealey et al, 2001). Li et al (2012) showed that the largest contributor to C&D waste in a commercial building is concrete waste (43.5%), followed by timber formwork (18.7%), steel bar (9.8%), brick and block (8.4%), mortar (8.4%) and tile (1.2%). This wastage rate is significant. Predominantly, C&D waste in construction is due to traditional practices in the industry, where stock 'shrinkages' are taken into account when estimating materials (Sealey et al, 2001). Other sources of waste in construction may come from the industry's internal inefficiency. These inefficiencies include, but not limited to, a lack of an integrated network for collection, utilisation and reuse of C&D waste materials (Fatta et al, 2003); a lack of standardisation or specifications of waste materials (Hadjieva-Zaharieva et al, 2003); lack of at-source waste management directives and capacities (Lu et al; 2011), lack of skills/poor workmanship and heavy reliance on traditional construction methods and materials (Hassan et al, 2012).

Another crucial factor that may have significant contribution to waste generation in construction is a lack of commitments and supports for waste minimisation from management and construction stakeholders (Teo & Loosemore, 2001; Hadjieva-Zaharieva et al, 2003; Hassan et al, 2012). It has been found that human behaviours such as attitudes and perceptions towards C&D waste can have significant impacts on the success of a C&D waste minimisation strategy (Teo & Loosemore, 2001; Kulatunga et al, 2006; Begum et al, 2006; Begum et al, 2008; Afroz et al, 2008). However, due to the fragmented nature of the construction industry and the disaggregation of

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roles/responsibilities between construction professionals, significant waste is still being generated in, and by, construction.

Waste is often viewed as inevitable part of construction (Osmani et al, 2008). As such, C&D waste minimisation has received a low priority in construction (Teo & Loosemore, 2001; Chong et al, 2009). This is particularly true during busy times such as in a construction boom, where designers and contractors are pressured to finish projects in the shortest time possible. The result is less time and resources are allocated to C&D waste management and minimisation (Teo & Loosemore, 2001). It has been reported that decisions made to at design stage could help reduce up to 33% of C&D waste in any construction project (Osmani et al, 2008). However, the reasons designers do not often implement waste reduction in the design process are due to external influencing factors such as clients' requirements and costs (Poon et al, 2004).

The above argument shows there is an urgent need to incorporate waste minimisation in building construction practices to reduce amount wastage currently being generated by the construction industry. It seems now is the right time for New Zealand construction to undertake this task because currently the country is experiencing a construction boom in Christchurch and Auckland.

2.1.3. Waste Minimisation Efforts by Construction

Recently, efforts have been spent to establish 'best practices' for reducing C&D waste (BRANZ, 2014). Notable New Zealand-based initiatives include 'Resource Efficiency in the Building and Related Industries' (REBRI) programme and New Zealand Zero Waste initiative. However, such programmes have yet to show tangible results. This lack of

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evidence may be a cause for the slow uptake of waste minimisation in New Zealand construction.

The review of literature has revealed that much recent effort has focused on identifying factors that may have significant effects on C&D waste generation. The result is a rich body of knowledge concerning the sources of waste in construction has been provided. Further, these investigations have collectively provided a glimpse into successes and failures in C&D waste management and waste minimisation.

However, most current emphases on C&D waste management and C&D waste minimisation remain on moderations of behaviours instead of looking for ways in which the totality of the system can work together to minimise waste (Teo & Loosemore, 2001). While focussing on the end-user is the easiest way to influence C&D waste – i.e. by using the power of the demand chain to affect the supply process, given the fragmented nature of the construction industry, this consideration would appear to be simplistic. It has been argued that such an approach can be enhanced through the incorporation of ‘systems view’ of behaviours (Seadon, 2010). It is anticipated that a systems approach will enhance the understanding around C&D waste minimisation, which in turns can be used as the basis for further developments in C&D waste minimisation.

2.2. Waste Minimisation - A Systems Perspective

As shown in Section 2.1.2, successful C&D waste minimisation strategies require both appropriate technical capabilities and commitments from the management (Wang et al, 2010; Lu & Yuan, 2011). Further, Chapter 1 shows that C&D waste management may

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also depend on the economics of such strategies (Tam & Tam, 2006; Tam, 2010). It has been argued that the traditional reductionist approach in solid waste management is no longer capable of handling the complexity required by modern waste minimisation programmes (Marshall & Farahbakhsh, 2013). In the reductionist view, waste management processes such as waste generation, waste collection, and waste disposal are treated as independent operations (Seadon, 2010, p. 1640). Due to this compartmentalisation, solutions for each process along this chain remain independent of each other and may not properly address the waste problem (Marshall & Farahbakhsh, 2013). By contrast, modern waste management and minimisation strategies require multi-dimensional considerations encompassing social, cultural, political, and environmental facets. Further, these considerations may be interlinked and interactive (Seadon, 2010). Therefore, a more holistic framework such as a systems approach is required to sufficiently address solid waste, including C&D waste, problems (Marshall & Farahbakhsh, 2013; Business Dictionary, 2015). In other words, the need for a systems approach in waste minimisation arises from the complexity of managing and minimising C&D waste streams.

The review of literature has revealed that the systems approach to waste minimisation is not widely practiced in the construction industry. On balance this is likely due to the fragmented nature of the construction industry. It has been widely reported that there is a lack of coordination between construction groups in C&D waste management (i.e. Fredricsen, 2003; Hu, 2011; Hassan et al, 2012). And as a result, C&D waste management and minimisation in construction is still ad-hoc (Teo & Loosemore, 2001). For example, construction designs often do not incorporate prefabricated components and assemblies that minimise waste (Jaillon et al, 2009). This is a missed opportunity

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because the use of prefabrication could significantly reduce C&D waste in construction – by up to 52% compared to traditional construction techniques (Jaillon et al, 2009).

Further, it has been reported that there are minimal interactions between the designers and the material suppliers and between the suppliers and contractors (Dainty & Brooke, 2004; WRAP, 2007, 2009, 2011). This lack of collaboration/interaction between key project partners is a significant reason for the continued over-ordering of construction materials as well as the continued wastage throughout the supply chain (Dainty & Brooke, 2004). These are a few potential issues that are extant in the ‘system’ that currently exist in the construction industry. For example, contractors are often incentivised by their suppliers to buy materials in bulk. By doing so, contractors can get greater discount rates from merchants and suppliers. In turns, this encourages the contractors to use materials without any disregard for recycling and reuse, as it is cheaper to buy new materials than to recycle and reuse similar materials.

The above arguments show that there is an urgent need for construction to implement a systems approach to address its C&D waste. However, given the lack of precedent cases in this area, the first step is to have a good understanding of C&D waste minimisation and current practices. Once such an understanding is achieved, appropriate strategies can be developed to ensure the systems-based C&D waste minimisation strategies work and deliver values to the intended construction stakeholders.

The following sections in this chapter will examine in detail concepts associated with C&D waste minimisation.

2.3. Research Framework

The requirement of the systems approach means that it is necessary to understand all facets of waste minimisation in the construction context. This includes overarching concepts such as ‘Green’ and ‘Sustainability’, as well as C&D waste-specific topics such as ‘Waste Minimisation’ and its objective: ‘Zero Waste’. It is anticipated that by reviewing literature in these topics, the researcher can build sufficient knowledge in, and understanding of, C&D waste minimisation. Moreover, it allows the researcher to identify challenges and issues that the industry faces in its quest to achieve zero waste.

To help discuss these related topics, this research introduces a framework to help review literature related to waste minimisation and zero waste systematically (see Figure 1 overleaf). This framework arises from the researcher’s need to have a holistic understanding of subjects related to C&D waste minimisation and zero waste. It is based on the researcher’s experience and understanding of the New Zealand construction industry. This literature review framework has allowed the researcher to gain a comprehensive understanding of subjects concerning C&D waste.

In this framework, each circle represents a study area (or ‘category’) that is relevant to C&D waste minimisation. These categories are: Green Construction, Sustainable Construction, C&D Waste Management, C&D Waste Minimisation and C&D Zero Waste. Each category is an area of study and can be discussed independently. However, it is necessary to contextualise the research topic in this manner to provide a good understanding of issues, challenges and opportunities in C&D waste minimisation.

In this framework, each circle represents a category; and each sub-category is eclipsed by a larger category (i.e. the outer circles). By employing this approach, the literature

pertaining to C&D waste could be systematically and thoroughly reviewed in a more structured manner than it would be otherwise.

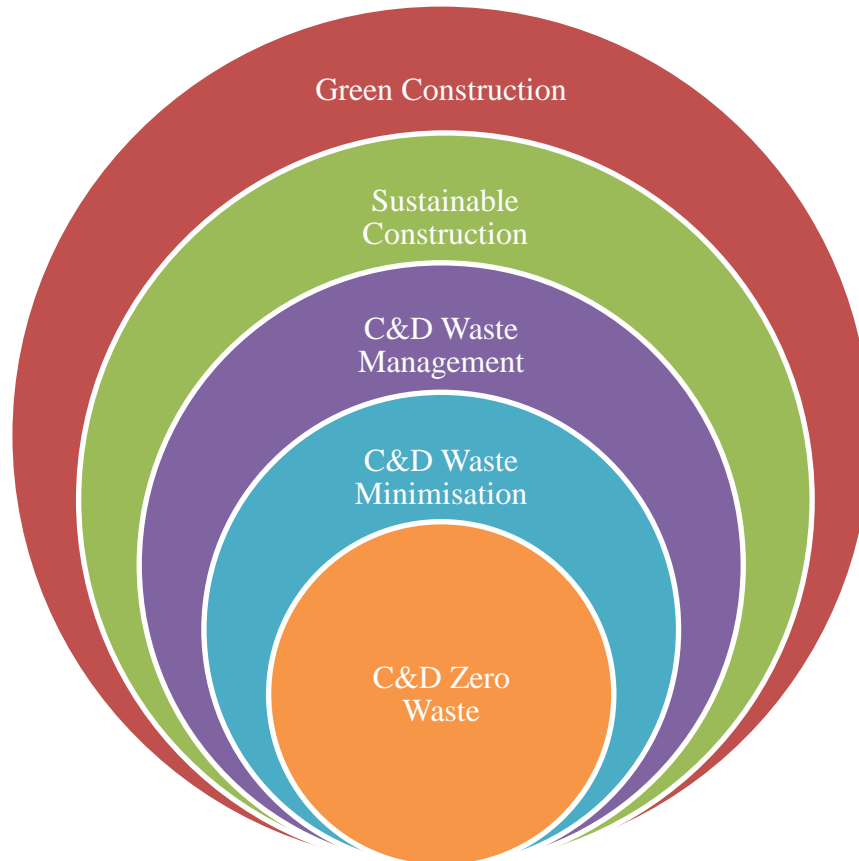


Figure 1: Holistic Approach to Understanding Zero Waste in New Zealand Construction

2.3.1. Relationships between Categories

Although it is debatable whether Sustainable Construction should be a subset of Green Construction or vice versa, in this study the former was chosen. Although there are many similarities between Green Construction and Sustainable Construction, these 2 concepts are not synonymous. The 'Green' concept focuses on the environmental aspects of doing business in construction. It aims to minimise environmental effects of

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construction by promoting 'green' practices, regardless of costs and social impacts. This consideration is a one-dimensional. Further, it can lead to many problems in construction, including inefficiency and long term liabilities. On the other hand, in 'Sustainable Construction', not only does the focus rest on the environmental aspect of doing business but it also takes in consideration the economic and social aspects of doing business. This means the concept 'Sustainable Construction' is more thorough in its focus than it is in 'Green Construction'. For this reason, in this study Sustainable Construction is considered a subset of Green Construction.

The relationships between other sub-categories are straightforward. 'Sustainable Construction' demands that C&D waste must be appropriately managed. This need leads to discussions on 'C&D Waste Management'. As such, C&D Waste Management is a subset of Sustainable Construction.

Similarly, C&D waste minimisation is a direct consequence of C&D waste management, because the former focuses on diverting waste from landfill while the latter focuses on more general waste disposal (which includes waste dumping among considerations) and waste treatment settings. Thus, the topic C&D Waste Minimisation is a subset of C&D Waste Management.

Finally, there must be a goal in C&D waste minimisation, and C&D zero waste is an appropriate target. Therefore C&D Zero Waste is the subset of C&D Waste Minimisation. The following sections will discuss each of the topics in Figure 1 in detail in this order.

Detailed discussions using this framework are structured as follows. Section 2.4 will discuss the 'Green' concept, including Green Construction; while Section 2.5 will focus

on 'Sustainability' and 'Sustainable Construction'. The Sections 2.6 and 2.7 will offer insights into 'C&D Waste Management' and 'C&D Waste Minimisation', respectively. And finally, Section 2.8 will discuss effort to date to achieve 'Zero Waste' in industries, including construction.

2.4. The 'Green' Concept

In this section, three areas related to the 'green' concept will be discussed. They are: Green Cities, Green Infrastructure and Green Construction/Buildings. These areas are relevant to this study, as they are related to the construction industry.

2.4.1. Green Cities

The 'Green City' is a relatively new concept (Kahn, 2006). It explores the relationships between urban developments and the natural environments and how to balance the developments in cities without having adverse effects on the natural environment.

It has been observed that urban environments often have distinctive biophysical features compared to rural areas (Gill et al, 2006). Urban areas have higher climates and hydrological variabilities due to the amplification of energies and increased surface runoffs of rainwater, respectively. Further, a significant amount of land in, and around, urban areas is exploited for roads and buildings. Recently, developments of land have increased significantly worldwide at the expense of the already-limited parks and other green spaces (Sandstrom, 2002). This increased development has in turns severely affected the urban biodiversity.

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Due to its focus on the urban environments, the 'Green City' concept has gained significant popularity in recent times, particularly important in densely populated areas (Sandstrom, 2002; Wolf, 2003; Gill et al, 2006; Kahn, 2006; Tzoulas et al, 2007; Vandermeulen, 2011; M'Ikiugu et al, 2012). As population and urbanisation grow, there are significant expectations and requirements from citizens for efficient and reliable infrastructure to deliver essential goods and services. In turns this has put significant pressures on land and infrastructure uses.

For its part, construction has put significant emphasis on delivering buildings and infrastructure for commercial, residential and industrial purposes in response to demands from its clients (Wolf, 2003; Matsuoka & Kaplan, 2008; Bomans et al, 2010). However, as the city population continue to expect to live in an environment with clean air and less pollution, construction is also required to adequately respond to this new expectation. Given the important role construction plays in urban development, green city seems an appropriate framework for construction to meet all requirements from its clients.

To date, much effort worldwide has been to explore and understand the green city concept in great detail. For example, Sandstrom (2002) investigated the applicability of green city and green infrastructure from a legislative perspective while Wolf (2002) viewed green space and green city from a social perspective. Although the approaches of these two researchers are different, they have found that there is still much work to promote and implement the green city concept.

Taking a different approach, M'Ikiugu et al (2012) developed a tool for planners using landscape metrics and geographic information system (GIS) to analyse urban green

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space (UGS). It was found that there is an urgent need for cities to incorporate green spaces into urban development (M'Ikiugu et al, 2012). To achieve this, there needs to be a paradigm shift that gives UGS the same or more weight than other physical development undertakings and policies (M'Ikiugu et al, 2012). M'Ikiugu et al's (2012) findings are relevant and important in the context of green city. This is because trees and green spaces are essential and can be regarded as a living system to support and enhance the quality of life for urban environments. Thus, it can be argued that by improving green space and green infrastructure, a city can fulfil its obligations to provide environmental, socio-cultural, and economic benefits to its citizens (Sandstrom, 2002; Wolf, 2003).

2.4.2. Green Infrastructure

'Green Infrastructure' is the upgraded concept of 'Urban Green Space' (Tzoulas et al, 2007). Originally, the term "green infrastructure" describes a network of natural green space such as forests, wetlands, waterways, wildlife habitats, parks and other conservation lands in and around urban and urban-fringe areas (Weber et al, 2006; Mell, 2008).

Like built infrastructure such as roads and utilities, green infrastructure provides essential ecological services necessary for city dwellers' well-being. Ecosystem services provided by green infrastructure include cleaning the air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants (Weber et al, 2006). However, the term 'green infrastructure' now has a meaning that is closer to sustainability goals that cities are trying to achieve through a mix of natural approaches (Foster et al, 2011). Examples of green infrastructure include

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green alleys and streets; urban forestry; green open spaces such as parks and wetlands; and adapting buildings to better cope with floods and coastal storm surges (Foster et al, 2011). Therefore, green infrastructure can be considered as a coherent planning concept comprising of all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas at all spatial scales (Sandstrom, 2002; Kambites & Owen, 2006; Tzoulas et al, 2007).

It has been observed that if proactively planned, developed, and maintained, green infrastructure has the potential for effective urban development by integrating economic growth, nature conservation and public health promotion (Tzoulas et al, 2007; Mell, 2008).

In practice, green infrastructure approaches consist of a mix of new concepts and technology and traditional “hard” infrastructures to create an enhanced level of urban sustainability and resilience (Foster et al, 2011). It has been reported that due to its adaptive capabilities, local governments have started to adopt green infrastructure in their planning and urban development (see, for example Wolf, 2003; Weber et al, 2006; Tzoulas et al, 2007; Schilling & Logan, 2008 and Foster et al, 2011).

The review of literature has shown that green infrastructure has been extensively studied worldwide. Kambites & Owen (2006) studied green infrastructure planning in the UK and identified a few essential attributes of green infrastructure planning. These attributes are connectivity in all green infrastructure planning processes; the need for a partnership, particularly involvement of local communities throughout the process; and the need to embed green infrastructure planning in democratic and statutory planning

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systems. Moreover, these findings appear to have international relevance and significance, not just particular to the case of the UK (Kambites & Owen, 2006).

Based on the British experience, many authors attempted to apply this concept to other parts of the world. Amati & Taylor (2010) focused on the Canadian context, and that of Toronto, to examine challenges in integrating the concepts green belts with green infrastructure. Conversely, Qureshi et al (2010) analysed the effects of ecological disturbances on public health due to high cutback in Karachi's green infrastructure. Both studies found that there is a need to develop a comprehensive urban greening strategy, which considers the needs and priorities of the population.

In the US, the green infrastructure concept is more welcoming and has been more widely practiced than the rest of the world (Wise, 2008). Wise (2008) reported green infrastructure is being up-taken in Seattle, Portland (Oregon), Twin Cities (Minnesota), Burnsville (Minnesota), Chicago, Milwaukee, Philadelphia, Washington D.C. and Kansas City. Gill et al (2006) investigated the role of green spaces and green infrastructure in the adaptation of cities to climate change. Through modelling, Gill et al (2006) could quantify the potential of the green infrastructure to moderate climate change impacts in towns and cities. Specifically, the biophysical features of green space in urban areas (trees, gardens or parks) provide vital ecosystem services for cities because they offer cooler microclimates to an area and reduce surface water runoff, and ultimately, offer cities a potential adapt for climate change (Gill et al, 2006). Similarly, Spatari et al (2011) used life cycle assessment (LCA) to analyse urban green infrastructure and found that if the concept implemented throughout an urban watershed, significant cost savings from energy usage can be achieved throughout a city's network of water pollution control facilities (Spatari et al, 2011). In a similar

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fashion, Vandermeulen et al (2011) showed that by investing in green infrastructure, not only can such investments make significant contributions to the environment but it also creates direct and indirect positive effects for a region.

However, it has been warned that creating green infrastructure is only the first step in urban planning (Hostetler et al, 2011). To promote and streamline green infrastructure, more funding and development is needed (Mell, 2008). This means everyone, from planners, to developers, to researchers, and residents, has a role to play in shifting from conventional development methodology to green infrastructure (Hostetler et al, 2011).

Overall, the review of literature has shown that to achieve green infrastructure, there needs to be willingness and appropriate strategies from governments and practitioners. The construction industry plays a key role to deliver green infrastructure to cities. And as implied by Hostetler et al (2011), the construction industry needs to shift its focus to 'greener' development paradigms to help deliver the green infrastructure objectives; and green construction is a solution for the construction industry to meet this requirement.

2.4.3. Green Construction

As discussed in Sections 2.4.1 and 2.4.2, 'Green Construction' plays a key role in delivering 'Green Cities' and 'Green Infrastructure'. In the construction context, the 'Green' concept focuses on construction practices that promotes environmentally-friendly designs and uses energy efficient materials and equipment to minimise the adverse effects brought by the construction process to the environment (Kubba, 2009; Levy, 2009; Kubba, 2010). This means green construction is 'a process of building structures using environmentally friendly resources while ensuring the building performs

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efficiently throughout its lifecycle' (Kats, 2003; Boyle, 2004; Haapio & Viitaniemi, 2008; Green Building Solutions, 2013).

However, it must be noted there is a significant difference between 'green buildings' and 'green processes'. While the former relies on a rating system such as LEED or Star Rating to be classified as 'green', it is the undertaking of the latter (i.e. to produce a building) that has the greatest impacts on the environment (Reznick Group, 2009; Green & May, 2003). In fact, Levin (2000) found that although the industry has steadily moved towards green building practices, there is little evidence showing such practices producing less overall environmental damage than the status quo. The result is that many dubious 'green' practices with undetermined environmental impacts have been accepted and become the norm in construction (Levin, 2000; Kats, 2003; Lam et al, 2010).

It has been reported that the 'Green Construction' concept has gained significant attention over the last decade due to their perceived positive effects on urban environments (Sandstrom, 2002; Wolf, 2003; Gill et al, 2006; Kahn, 2006; Tzoulas et al, 2007; M'ikiugu et al, 2012). This is because urban growth has put immense pressure on land uses in cities worldwide; and the 'green' concept can help calibrate the environmental changes caused by such growth (Vandermeulen, 2011).

However, it has been argued that green buildings could be substantially more costly than conventional ones; so, from the cost-benefit perspective, green construction might not be attractive to conventional builders or developers (Kats, 2003). This perception has been a substantial obstacle to a wider adoption of the green methodology.

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Despite this drawback, the review of literature to date has shown that green construction has had positive impacts on construction (Ofori, 2000; Ahn & Pearce, 2007; Build It Green, 2007; Nielson et al, 2009; Nahmens, 2009; Banawi, 2013). For instance, Ofori (2000) applied the green idea to construction in Singapore and found that green procurement with stringent requirements for environmental control and performance criteria had significantly positive effect on the supply chain of Singaporean construction. At the same time, Nahmens (2009) contended that green construction is a natural extension of the 'Lean Construction' concept, evidenced by the fact that the removal of C&D waste from construction processes has become a norm in construction projects. This argument is dubious because although there are similarities between the two concepts, green construction places great emphasis on environmentally-friendly construction practices. On the other hand, lean construction focuses on minimising wastages in construction processes.

Lam et al (2010) investigated factors that may have significant effects on the implementation of green specifications in construction. Using a cross-sectional survey regarding green specifications conducted in Hong Kong in 2007 and extensive literature, the study found five independent factors affecting green construction, including 1) technology and techniques, 2) reliability and quality of specification, 3) leadership and responsibility, 4) stakeholder involvement, and 5) guide and benchmarking systems (Lam et al, 2010). Upon further analysis, it was found that different stakeholders tend to have different emphases on the relative importance of these five factors (Lam et al, 2010). Kats (2003) and Lam et al (2010) show that there are many things to consider when implementing the green construction concept.

Overall, it has been shown in literature that significant benefits could be gained by the construction industry by simply being 'greener' (Tam et al, 2004; Ahn & Pearce, 2007; Venus, 2011). Not only do these benefits come in term of environmental credentials, but also in term of profitability. Therefore, there is a case for the construction industry to take part in the 'green' movement; and the first step is to manage its waste output.

2.5. Sustainable Construction

2.5.1. Sustainability and Sustainable Development

'Sustainability' is defined as "the ability to be sustained, supported, upheld or confirmed" (Dictionary.com, 2015). In other words, sustainability is the capacity of a natural-social system to maintain and increase values of environmental, social or economic components (Manzini et al, 2011). It has been observed that currently there are various definitions of 'sustainability'; each with its own meaning depending on the context used (Glavic & Lukman, 2006; Brochner et al, 2010). As such, 'sustainability' can be open to a wide range of interpretations. A complete history of sustainability is provided by Chiu (2012).

Sustainable development arose in the 1980's of the 20th century. In a global context, 'sustainable development' mandates that any economic or social developments should improve the environment (Hendler, 1980; Todorov & Marinova, 2011). Over the last few decades, this concept has developed from a global political process into a holistic framework that touches every part of society (Hendler, 1980; Myers, 2005). Broadly, sustainable development is defined as a process of achieving three interrelated components: social equity, environmental protection, and economic growth in urban

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development without major compromises to the future generations (WCED, 1987; Khalfan, 2006; Manzini et al, 2011). These components are often known as the 'triple bottom line'. However, sometimes other components such as political, institutional and/or technical capacity are also considered (Hill & Bowen, 1997).

To date, significant efforts have been made to understand sustainable development. Hueting & Reijnders (2004) proposed sustainability indicators with additive characteristics covering economic, social and environmental aspects. Similarly, Manzini et al (2011) considered environmental, anthropo-centric and bio/eco-centric dimensions in sustainability and sustainable development. These studies are useful, as they are the first step to help understand sustainable development.

2.5.2. Sustainable Development in Urban Environments

The emphasis of sustainability and sustainable development is on long-term benefits to society (Seabrooke et al, 2004). Currently the greatest amount of world resources is consumed in urban environments. About 78% of carbon emissions come from fossil fuels burnt to make cement; 76% of industrial wood worldwide is used in metropolitan areas; and 60% of the water that runs through pipelines is consumed by cities (Mora, 2005). As the driving power for economic and social developments of most countries, cities constantly require significant resources to fuel its appetite. Therefore, it is appropriate to consider sustainable development in urban context.

Often professionals such as architects, planners, engineers, philosophers, artists, sociologists, and economists all have different views on sustainability and sustainable developments. This is due to their training and practices of these respective disciplines, thus solutions put forth by each profession. Therefore, to ensure truly sustainable

solutions can be delivered and applied in the urban environments, there is a need for holistic frameworks to encourage cross-disciplinary interactions between various professions and stakeholders (Jones & Jones, 2007). Sustainability and sustainable development hence encompasses technological means for dealing with environmental issues and includes socio-economic and philosophical considerations (Jones & Jones, 2007).

2.5.3. Sustainability in Construction

Recently, sustainability has been widely adopted by the construction industry worldwide (Saparauskas & Turskis, 2010). Originally, the term 'sustainable construction' was used to describe the goal of construction of attaining 'sustainability' (Edum-Fotwe & Price, 2009; Chen & Chambers, 2010). This means sustainable construction can be thought of as 'the industry's capacity to meet, maintain and improve social, environmental and economic values for its stakeholders and participants'.

Sustainable construction is closely associated with green construction in many aspects, especially around environmental responsibilities of construction businesses (Khalfan 2006). But unlike green construction, sustainable construction also considers the economic social and cultural aspects of doing business in construction.

It has been observed that there is an important distinction between 'sustainability' and 'sustainable construction'. The former is the ultimate objective of sustainable construction while the latter is the process of achieving such an objective (Abidin & Pasquire, 2005). To achieve sustainability, the industry must promote cross-disciplinary collaborations between construction partners (Hill & Bowen, 1997; Persson & Olander, 2004; Khalfan, 2006). And such collaborations start well before construction: from

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planning and design stages and continue throughout the construction of the project. The collaborations may even extend to the management of the building's serviceability during its lifetime (Kubba, 2009).

In theory, sustainable construction processes would force the construction industry to rethink of its environmental responsibility, social awareness, and economic profitability. However, due to the fragmented nature of the construction industry, it is not easy to apply this concept to practice (Adetunji et al, 2003; Lorenz et al, 2006; Chong et al, 2009; du Plessis, 2010). In fact, there is a wide range of factors that can affect sustainability in construction. They range from micro-level such as specific strategies to address sustainability and/or the involvement of stakeholders to macro-level such as economic and/or legal systems which the industry operates in (Bon & Hutchinson, 2000; Adetunji et al, 2003; Chen & Chambers, 2010).

Besides, construction companies are resistant to changes, particularly around adopting sustainability practices. This is mainly due to the perceived high costs associated with such changes (Revell & Blackburn, 2005). This shows economic considerations of sustainability are high in the agenda within the construction industry. Given that construction is a labour-intensive-and-low-profit-margin industry, it is understandable that economic considerations remain at the forefront of its agenda.

Therefore, to promote and encourage the uptake of sustainable construction, the construction industry must first effectively address the economics of sustainability strategies. This study contributes to this aspiration by developing a framework to evaluate the economics of minimising C&D waste. It is anticipated that by understanding the economics of C&D waste minimisation, appropriate strategies can be

made to promote waste minimisation and advance sustainability practices in New Zealand construction.

2.5.4. Sustainability Understanding in Construction

It has been reported that the lack of understanding of sustainability is the main cause for the lack of progress in sustainability (Hall & Purchase, 2006). Recently, significant effort has been made to achieve a good understanding of sustainability in construction. Sustainability considerations are thought to encompass four aspects: environmental, economic social and cultural dimensions (AUT, 2015). But in construction, sustainability considerations have mostly focused on environmental aspect because the industry is one of the largest users of natural resources and one of the largest polluters worldwide (Hueting & Reijnders, 2004). It has been argued that by influencing construction's performances in the environmental aspect will force the industry to place greater value on other dimensions (economic and/or social) (Haapio & Viitaniemi, 2007; Ding, 2008).

On contrary, it has been argued that the most effective approach is to influence the economic aspect (Bon & Hutchinson, 2000). This is because the construction industry is mostly made up of small and medium companies with limited resources (Myers, 2005). As a result, small companies do not have the capacities to develop and implement sustainability measures due to the high costs associated with such implementations (Revell & Blackburn, 2005). Besides, as sustainable construction is an incremental process, this requires construction companies to have long-term strategic goals (Bourdeau, 1999; Chong et al, 2009). But construction projects are short-term by nature. This discrepancy does not permit construction companies, particularly small companies, to implement sustainability measures in all their projects. Thus having a

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market oriented economic-based system will likely encourage construction companies to uptake sustainability practices and measures (Bon & Hutchinson, 2000).

To date, many studies have focused on developing metrics to help understand construction's aspiration to achieve sustainability. For instance, Rijsberman & van de Ven (2000) developed a system consisting of four basic elements to assess the sustainability aspect of design and management of urban water systems. Hueting & Reijnders (2004) proposed sustainability indicators with additive characteristics to measure economic and social elements sustainability. Similarly, Persson & Olander (2004) developed a method to estimate stakeholders' views on sustainability of construction projects. Fernández-Sánchez & Rodríguez-López (2010) developed a methodology to identify, classify and prioritise sustainability indicators based on risk management standards. These studies have been helpful in providing construction resources to achieve sustainability.

Currently there are numerous sustainability indicators used in the building sector worldwide (Fernández Sánchez, 2008). They can be broadly divided into 4 main categories Environmental Impact Assessment tools such as Life Cycle Analysis (LCA) or Criteria-based tools (CB) or a combination of LCA and CB; Economical Assessment tools such as Life Cycle Costs (LCC), Cost-Benefit Analysis, Financial Appraisal (FA), Social Financial Appraisal (SFA), Cost-Revenue Analysis (CRA), Cost-Benefit Analysis (CBA), and Social Cost-Benefit Analysis (SCBA); Social and Cultural Assessment tools such as Social Surveys, Questionnaires, Interviews, Statistics; and Multi Criteria Analysis (Rijsberman & van de Ven, 2000; Persson & Olander, 2004). However, it is difficult to compare these tools because each was designed for assessing a specific building type (Haapio & Viitaniemi, 2007). Another problem is each environmental

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assessment tool was developed for a specific purpose (research, consulting, decision making and maintenance) for a different user group (designers, architects, researchers, consultants, owners, tenants and authorities). This means there exist errors in the underlying assumptions and definitions used, their calculations. Consequently, these errors could significantly affect the assessment results of these sustainability tools.

Perhaps the greatest impacts on understanding sustainability in construction can be achieved via education (Murray & Cotgrave, 2007). Currently significant emphasis in construction education at tertiary level remains on the technical know-hows of their respective disciplines (e.g. architecture, civil engineering, quantity surveying, surveying). There is little focus on construction sustainability in these syllabuses although construction sustainability plays a big part in the professional practices of these disciplines. The result is students, upon completing their formal education at tertiary providers, will have to be trained in sustainability by their employers. This double-handling of education is a significant waste to the industry and is, hence, not ideal from the sustainability perspective.

In response to this demand, many higher education institutions have incorporated sustainability in their education programmes (Wang, 2009). However, currently there is no consensus on the operational requirements on sustainability in these programmes. Instead, materials taught in sustainability courses are based on the instructors' experiences. Further, there is a degree of resistance from education providers to include sustainability into their teaching curricula (Murray & Cotgrave, 2007). Therefore, there is an urgent need for comprehensive guidelines and strategies for education providers to prepare students with sustainability knowledge and techniques (Wang, 2009). In a case study in New Zealand, Kestle & Rimmer (2010) assessed a student's

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ability to apply relevant and defensible real-time sustainable design and construction to a concept and found that given sufficient freedom, students could demonstrate an appropriate level of understanding of sustainability.

Overall, construction's lack of aspirations to achieve sustainability is universal. Therefore, there is a need for a major cultural shift to enhance the sector's respect for sustainability (Fellows and Liu, 2007; Yip & Poon, 2009). By understanding the culture of the construction industry, appropriate strategies can be implemented to enhance the uptake potentials for construction sustainability. One such strategy is to assess the economic imperatives of minimising construction's C&D waste outputs. It is indeed a fundamental rationale for the study reported in this thesis.

2.6. C&D Waste Management

2.6.1. Waste Management Overview

Waste management is a process involves 'collect, transport, process, dispose and monitor waste materials to reduce their effect on human health and/or local amenity' (Ecolife, 2015). Waste in this sense is materials that are produced by human activities and can be solid, liquid, gaseous or radioactive. It has been observed that waste generation increases as population and economic developments grow. This means improper handling of waste can pose significant risks to human health and the environment (EPA, 2002). Adverse effects of uncontrolled waste disposal and improper waste handling include water and soil contamination, increased insect and rodent populations and safety hazards such as fires or explosions.

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The management of solid waste is linked to ‘sustainability’ because not only can a successful waste management programme help enhance living environments for communities, it can also help reduce the reliance on virgin resources needed for the community to function (Hogland & Marques, 2007). There is a long-held view that materials that are thrown in the trash bins have no values – i.e. it is ‘waste’. However, from an ecological perspective, leftover materials can be viewed as “resources” because they can be reused and/or recycled to make new products. In this view, the ‘waste’ problem hence becomes an opportunity for resource extraction (Ecolife, 2015).

Since 1960’s, efforts have been made to develop comprehensive measures to effectively address the waste problem. This culminated to ‘Integrated Waste Management’ or IWM, as shown in Figure 2. (Nordone et al, 2009). IWM is a strategy that aims to combine all fragmented facets of waste management into a holistic framework. It is thought that this waste management paradigm can provide environmental sustainability, economic affordability and social acceptance for a region (EPA, 2002; Nordone et al, 2009; Ecolife, 2015). This systems approach is different to the traditional waste management paradigm because it allows for appropriate strategies to be developed to minimise the economic costs while maximising the environmental and social benefits of a region.



Figure 2: Integrated Waste Management. Source: EPA (2002)

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To date many studies have investigated solid waste management worldwide. Hogland & Marques (2007) argued that the basic requirements for a successful waste management programme are technology and standards for occupational health and safety (OH&S). Although this view is valid, it is only likely valid for developed countries, as the costs of purchasing the technologies and the costs of developing OH&S standards are perceived as being too high by less-developed nations. However, Shekdar (2009) recently found that the general waste management trend in both developed and developing economies in Asia is in line with that elsewhere in the world. It was reported that a handful of developed Asian countries such as Japan and South Korea are having specific waste minimisation strategies in place; while the rest are aiming to incorporate the 3R methodologies (reduce, reuse and recycle) in their practices (Shekdar, 2009).

Nguyen & Schnitzer (2009) investigated solid waste management in Southeast Asia and proposed a pragmatic model for managing waste for countries in this region. When applied to a case study in Vietnam, it was found that the model, 'A zero emissions agro-based industrial ecosystem (AIZES)', is suitable for the food processing industries. Further, AIZES shows that waste can be reused as resources (Nguyen & Schnitzer, 2009). There are a number of fundamental differences between waste management models proposed by Shekdar (2009) and Nguyen & Schnitzer (2009) respectively: whereas the former is conceptual and can provide a framework that Asian nations could adapt to their needs, the latter is practical and applicable to less-wealthy developing nations of Southeast Asia. However, these two models can complement each other. Further, when used together, they can provide a good framework for solid waste management.

2.6.2. Solid Waste Management in Construction

In construction, C&D waste can have significant impacts on the sustainability aspiration of the whole sector. As mentioned in Section 2.5, most virgin materials currently being mined is consumed by the construction industry. Any wastage generated by construction represents a significant dissipation of resources (Hu, 2011). The fact that C&D waste makes up between 10% and 36% of all landfill waste worldwide means that construction has a significant problem with its waste (Kartam et al, 2004; Tam, 2007; Yuan & Shen 2011; Hu, 2011; Hassan et al, 2012). The problem with C&D waste stems from the fact that it is generated at every stage in the life of a structure (Conlin, 2012; Hassan et al, 2012). Further, C&D waste can contain many hazardous materials from chemical and industrial treatments (Wang et al, 2010). This means when C&D waste is disposed of into landfill it can have major negative impacts on the environment due to chemical leachate. As a result, there is an urgent need for the construction industry to manage its solid C&D waste outputs.

2.6.2.1. Classification of C&D Waste

C&D waste can be divided into 2 categories: inert and non-inert materials. Using the European waste list system, these two broad categories can be broken down to eight C&D waste types: 'concrete, bricks, tiles and ceramics', 'wood, glass and plastic', 'bituminous mixtures, coal tar and tarred products', 'metals (including their alloys)', 'soil (including excavated soil from contaminated sites), stones and dredging spoil', 'insulation materials and asbestos-containing construction materials', 'gypsum-based construction material' and 'other construction material' (Lu et al, 2011). Similarly, New Zealand has its own classification consisting of nine main types of C&D waste. These

classifications are useful because they allow for effective tracking and accurate measurements of material wasted in construction projects (Fatta et al, 2003; Osmani et al, 2008; Osmani, 2011; Yuan & Shen, 2011).

2.6.2.2. *Recent Investigations in C&D Waste Management*

To date there have been several studies aiming to promote the management of solid C&D waste in construction worldwide. For instance, Jaillon et al (2008) found that waste can be reduced significantly using compared to the conventional stick-built system. It has been reported that up to 52% of C&D waste could be reduced using prefabrication (Jaillon et al, 2008). This means a wider use of prefabrication could significantly reduce the amount of waste generated in the Hong Kong building industry. Similarly, Poon et al (2004) provided a detailed framework for managing and minimising building waste. As evidenced by its successful applications in five housing projects, this framework could potentially benefit the construction industry significantly (Poon et al, 2004). Kofoworola & Gheewala (2009) developed a useful model to quantify the amount of C&D waste generated in Thailand's construction industry. With appropriate modifications, this model could be useful, and applicable, to New Zealand construction. However, this model lacks necessary rigour due to it not being applied to many cases. This is the model's weakness and cautions are needed when applying it to New Zealand. In Spain, a waste management model called the Alcores model was introduced to control, treat and reuse C&D waste in real time (Solís-Guzmán et al, 2009). The Alcores model is more useful than one proposed by Kofoworola & Gheewala (2009) in that it has been successfully tested in Seville. But again, cautions need to be taken when attempting to implement this model in New Zealand because calibrations or modifications might still be required.

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Recently, Llatas (2011) introduced a model for quantification of project construction waste in accordance to the waste list of Europe. This model is superior to both Solís-Guzmán et al (2009) and Kofoworola & Gheewala (2009) because it is more systematic and structured in its approach than the previous 2 (Llatas, 2011). Specifically, Llatas (2011)'s model provided a classification system of C&D waste and related variables such as quantification factors for building elements (constructive characteristics and building materials). Another advantage of Llatas (2011)'s model over the other 2 models is that it can be easily adapted for use in other countries without too much tweaking and users can use create a C&D waste database from this model for monitoring purposes (Llatas, 2011).

2.6.2.3. C&D Waste Management Systems Dynamics

With the development of advanced computer technologies, an increasing number of authors have opted for simulations to study C&D waste (see, for example Shen & Tam, 2002; Love et al, 2002; Hao et al, 2007; Osmani et al, 2008; Osmani, 2011; Lu et al, 2011; Li et al, 2012; Yuan, 2012 or Ye et al, 2012). Of all simulation modelling tools, systems dynamics seems to be the preferred choice. This is perhaps due to systems dynamics' ability to deal with complex issues involving social, economic and their interactions (Ding, 2007; Ye et al, 2012). It was found that systems dynamics can aid decision makers and practitioners to understand the complexity of information and processes in managing C&D waste (Hao et al, 2007). Moreover, systems dynamics could deepen the understanding about relationships in C&D waste management/reduction strategies C&D (Yuan et al, 2011). For example, Zhao et al (2011) applied systems dynamics to study the economic feasibility of a C&D waste recycling centre. It was found that major factors affecting economic feasibility of the

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project include unit cost and potential profits of the plant as well as additional revenues from location advantage (Zhao et al, 2011).

Although systems dynamics is a powerful tool, it is unsuitable for this PhD study. To successfully use a systems dynamics simulation, there is a requirement for reliable quantitative and quantitative data (Hao et al, 2007). Qualitative data are often collected via series of workshops or in-depth discussions while quantitative information must be presented in a clear and consistent format. However, the dynamics of this specific research, i.e. evaluating economics of C&D waste management strategies in New Zealand, means that to utilise systems dynamics as a mean of solution would expand the scope of the data acquisition process to make it unrealistic for the problem as defined.

2.6.2.4. Challenges and Opportunities in C&D Waste Management

In theory, waste management practices differ between construction types (e.g. residential, industrial and commercial) and between locations (e.g. developed countries and developing nations). However, in practice, waste management strategies like Waste Hierarchy, Source Reduction, Extended Producer Responsibility or User/Polluter Pays Principle are often implemented, as they can ensure waste generators meet their obligations under legislative requirements (BMA, 2009).

It has also been reported that the applications of C&D waste management have had varying degrees of success. McDonald & Smithers (1998) found that when compared with a similar project, waste-focussed projects could offer the stakeholders substantial savings. This shows that by having a well thought-through waste management plan can offer significantly benefits. McDonald & Smithers' (1998) results was later supported by

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Shen & Tam (2002) and later Tam (2007), with both studies confirmed that having a waste management plan in construction can significantly improve the success rates of reducing and reusing C&D waste.

However, the main barriers for implementation of C&D waste management are 1) the lack of incentives offered to contractors; and 2) the relatively high costs associated with such implementations (Shen & Tam, 2002; Kartam et al, 2004; Tam, 2007). Due to these barriers, construction still has significant impacts on the environments. For instance, in the Hong Kong construction industry in 2004, as high as 42 projects under study (out of 69) did not have any measures to collect and separate C&D wastes while 44 projects did not use recycled building materials in any form (Wong & Yip, 2004). The review of literature to date has revealed that cost and financial considerations related to C&D waste management remain universal and unchanged in the psych of people involved in construction across the world. However, if the construction industry is committed to managing its C&D waste outputs, it can be postulated that savings such as those reported in McDonald & Smithers (1998) are achievable.

An additional benefit of C&D waste management that is often ignored is a close relationship between C&D waste management and onsite productivity. Dainty & Brooke (2004) found that when waste management programmes were used on high-profile projects, productivity, site safety and project profit margins were all achieved. The benefits of a good C&D waste management could also extend beyond the construction sector (Peng et al, 2010). It has been reported that a recovery and recycling of C&D waste programme could achieve two goals: first it created more jobs for the local population in Thailand; and second, at the same time it reduced the energy consumption in the same location (Kofoworola & Gheewala, 2009). Therefore, for a

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waste management programme to succeed, the focus should rest on long-term benefits to be gained instead of the associated short-term expenses (Shen & Tam, 2002).

Overall, there have been many applications of C&D waste management in construction. However, the degree of success varies significantly from project to project. This is due mainly to the fragmented nature of the construction industry. Nevertheless, such efforts are the positive sign, as it shows the sector has realised the importance of, and its responsibilities for, managing impacts of its operations. However, to ensure a full understanding of C&D waste management is achieved, there is a need to show that significant economic values can be generated from managing C&D waste. This is indeed a fundamental rationale for the study reported in this thesis.

2.7. C&D Waste Minimisation

As presented in the Figure 1, C&D waste minimisation is a sub-category of C&D waste management. Currently, there is an urgent need for the construction industry to rethink its C&D waste management strategies. Predominantly, C&D waste results from internal industry processes, mostly from the sector's requirements, and waste, of natural resources (Osmani, 2011; Hu, 2011). Waste minimisation can arguably help construction to be more efficient and sustainable long term.

2.7.1. Proposals for C&D Waste Reduction

The analysis of the literature body collected for this research has found that recent effort has mostly focused on the following 10 areas: Waste quantification and evaluation, Waste reduction by design, On-site construction waste sorting methods/techniques, Data collection models (flows and mapping of wastes),

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Improvements of on-site waste management practices, Reuse/recycle of construction waste, Benefits of waste minimisation, Waste minimisation guides, Attitudes towards construction waste, Comparative waste management studies.

These findings are consistent with those of Osmani's (2012). The three research themes identified in Osmani (2012) but were not included here are: 'Procurement strategies to suit waste minimisation'; 'Impact of legislation on waste management practices' and 'Development of on-site waste auditing and assessment tools'. This minor deviation is due to the different approaches of the two studies: Osmani (2012)'s study focused on policies of C&D waste management and minimisation; whereas the research contained in this thesis focuses on economics of C&D waste minimisation.

It has been suggested that C&D waste minimisation could be achieved by having good relationship with stakeholders throughout the project life (Farinan & Caban, 1998; Treloar et al, 2003; Dainty & Brooke, 2004; Khalfan, 2006; Kubba, 2009). In the researcher's opinion, this is idealistic. In theory, this idea could significantly reduce onsite waste. However, in practice it is difficult to attain due to the industry's fragmentation. Besides, the applicability of this idea in construction is currently unclear. The fragmentation problem in construction is nothing new. For this to work, it will require a total change in the industry's mind-set.

The fragmented nature of construction is known to be the main hindrance for the implementation of such a collaborative framework. As construction is mostly made up of small construction companies working in a low profit margin and competitive market, time and costs are often at their key considerations. Often a collaborative framework such as one proposed by the above authors requires significant investments, in terms

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of time and money, from the involved partners. Therefore, small construction companies may be deterred by this idea. However, this observation is entirely based on the researcher's experience and knowledge in New Zealand construction. But the lack of literature on this subject matter means that there is an urgent need for investigations into this area. Such an investigation is worthwhile because it can provide construction a good understanding of relationship between sizes of construction companies and willingness to participate in collaborative framework to reduce C&D waste in the residential construction sector. This understanding can in turns help the construction industry to develop appropriate strategies to enhance the uptake of C&D waste minimisation in the construction industry.

Similarly, Saunders & Wynn (2004) suggested that having appropriate training for site personnel could significantly improve reduce waste. Although Saunders & Wynn (2004)'s C&D waste reduction proposal is not new, it requires a significant effort and commitment from the industry. Currently in construction, training and education is a costly component for companies so it is often not done systematically to minimise on-going costs. Such one-off training may not be effective, as it lacks the depth and context to properly educate tradesmen of values and benefits of waste reduction. Hence, there must be a concerted effort by all stakeholders for such a training programme to be effective. As an example, Lingard et al (2010) showed that goal setting and feedback should be included in a waste management programme because they can help improve the project's overall efficiency and waste reduction performances.

2.7.2. Recent C&D Waste Minimisation Programmes Worldwide

In terms of programmes to help the construction industry address C&D waste minimisation, there have been several waste minimisation programmes available worldwide. Some typical examples include SMARTWaste (McGrath, 2001) or REBRI (BRANZ, 2013). However, one thing that has impeded the uptake of tools such as SMARTWaste or REBRI is the construction industry's reluctance to implement new ideas and systems. One exception is the case in New South Wales, Australia, where an umbrella waste management programme called Sustainability Advantage has been in operation and achieved critical successes not only in construction but also in other sectors (Environmental NSW, 2014).

More practically, Lingard et al (2010), Hu (2011) and Osmani (2011) showed that waste could be significantly reduced by implementing integrated design and construction. Similarly, Treloar et al (2003) suggested techniques such as life-cycle analysis (LCA) or life-cycle costing (LCC) could be employed at early stages of the construction process to inform stakeholders of values of C&D waste management. Although such whole-of-life perspectives are useful, it is unclear in Treloar et al (2003) that they were used in residential construction, i.e. the focus of Treloar et al (2003)'s study. Perhaps LCA and LCC are more beneficial for decision-makers in large construction projects than they are in smaller ones, e.g. residential construction. But currently there is no way to verify this assumption, as little evidence can be found in the body of literature for this study. This is a gap in knowledge and future studies can be undertaken to explore this area.

2.7.3. Lean Construction as a C&D Waste Minimisation Method

In the last 25 years, significant emphasis has been put on Lean Construction as a way to minimise C&D waste. Lean construction is an adaptation of lean manufacturing principle to construction (Arleroth & Kristensson, 2011). There are 3 overarching lean construction frameworks: Last Planner, Target Value Design, and Lean Project Delivery System (Ballard, 2000; Howell, 2001; Macomber & Barberio, 2007; Cleves & Michel, 2007; Ballard, 2008; Ballard, 2008; Al Sehaima et al, 2009; Hamzed & Bergstrom, 2010; Zimina & Pasquire, 2012; O'Connor & Swain, 2013). Recently, several authors have introduced other techniques to be used in conjunction with Lean Construction. These techniques include Concurrent Engineering (Paez et al, 2005) and Building Information Modelling (Khanzode et al, 2006; Osmani, 2011; Coates & Kaushik, 2013).

Overall, it has been found that used correctly, lean construction can offer significant benefits to construction while reducing unnecessary waste (see, for instance Soward, 2007). Table 2 below indicates the project stages where these 3 frameworks have greatest impacts.

Table 2: Lean Construction and its Impacts

Lean Construction Method	Stage of greatest impacts
Last Planner System	Planning Design
Target Value Design	Design Procurement
BIM Integration Life-Cycle Considerations	Design Construction
Lean Project Delivery System	Manufacturing (onsite and offsite) Construction
Concurrent Engineering	Manufacturing Construction

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Despite the benefits that lean construction can offer, the uptake of this concept in construction has been slow. Currently there is no argument and/or explanation as to why this is the case. This is a knowledge gap that needs to be addressed urgently. Perhaps this knowledge gap is a factor that contributes to lean construction not being viewed as an attractive option for construction companies, as it fits into the ‘too-much-work-to-implement-but-commercially-uncertain’ category. Commercial uncertainty in this sense means that construction companies may view lean construction as a novelty method, i.e. one which does not offer them significant competitive advantages over their competitors simply by implementing it. This shows that in order for lean construction, or any waste minimisation-focussed systems, to be accepted and implemented by the construction industry, they should offer construction companies compelling economic reasons for implementation.

However, the review of literature to date has revealed there is a lack of tools and techniques to aid such economic considerations. This is another gap in the body of knowledge and one that needs to be addressed urgently. An understanding of factors impeding the widespread uptake of lean construction would help the construction industry to establish appropriate strategies to address such factors. It is anticipated that once lean construction is used by the construction industry, it can help the industry to address its C&D waste issues.

Despite its usefulness in accounting for C&D waste, lean construction is not a suitable method for this study. The dynamics of this research means that effort should be focused on developing an economic evaluation framework to assess the economics of C&D waste management strategies in New Zealand. This requirement means that to

employ lean construction as a mean of solution would expand the scope of the data acquisition process to make it unrealistic for the problem as defined.

2.8. Zero Waste

According to the conceptual C&D waste model presented in Figure 1, zero waste is the goal of C&D waste minimisation. This is also a universal and accepted understanding worldwide (Curran & Williams, 2012). Theoretically, 'zero waste' is a philosophy that aims to alter the current patterns of resource usage to minimise and reduce waste to zero (Whitlock et al, 2007; Connett, 2008; Young et al, 2010). However, currently there is no single definition of 'zero waste' and each author defines 'zero waste' differently to suit their own agendas (Phillips et al, 2011). This is a weakness of this theory.

In theory, zero waste can be achieved through 100% recycling or reusing materials. But in practice, 100% efficient use of materials is not possible. So, zero waste is understood as a new standard for systems efficiency and integration (Whitlock et al, 2007; Curran & Williams, 2012). In this context, waste can be thought of as 'residual products' or 'potential resources'. This means zero waste is a logical aspiration of sustainability.

2.8.1. Recent History

The term "zero waste" was first used publicly as the name of a company, Zero Waste Systems Incorporated (ZWSI), in 1974 in Oakland, California (Palmer, 2013). ZWSI' main activity was trading reusable laboratory chemicals in California as well as repackaging and reselling by-products from other industries (Zaman & Lehmann, 2011). As ZWSI was the only company in the world working in this business at that time, it was

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well-recognised internationally (Palmer, 2013). Consequently, the term Zero Waste has been widely used as a vision and goal for society (Palmer, 2013).

However, zero waste is sometimes considered as a direct result of Integrated Waste Management (ZeroWaste, 2011). In fact, a complete history of Zero Waste was provided in a report funded by the European Economic Commission (ZeroWaste, 2011).

Since 1980's, 'zero waste' has become a powerful environmental initiative worldwide (Snow & Dickinson, 2001). In New Zealand, the zero-waste concept has been widely accepted since its introduction, with over one third of New Zealand's local authorities have now set targets of zero waste to landfill (Snow & Dickinson, 2001).

From its conception, the 'zero waste' philosophy has challenged people's understanding and practices around waste management and waste minimisation (ZWA, 2013).

In the 'traditional' waste minimisation framework, majority of waste is often disposed of in landfill or incinerators. For example, it has been reported that in the USA alone, 7.6 billion tons of non-hazardous industrial waste were generated and managed annually in landfills (GM, 2012). Not only is this approach wasteful, expensive and harmful for environment, it has not kept pace with the scale, persistence and toxicity of the waste (ZWA, 2013).

To the contrary, zero waste suggests that 'waste' should be thought of as 'residual products' or 'potential resources' in a continuous, integrated, closed-loop system.

By reconceptualising waste as resources, society in general is in a win-win situation. This is because not only do zero waste practices support employment, business

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innovation and ‘green growth’, such practices can also help significantly reduce energy and water usage, green-house gas (GHG) emissions, pollution and loss of bio-diversity (AUMA, 2012). Moreover, waste, now viewed as resources, can be conserved, used efficiently and recycled back into the economy. Opportunities that zero waste can offer include reduced costs, increased profits, and reduced environmental impacts when using these ‘resources’ as inputs to natural or industrial systems. This further enhances the wealth of the society (ZWA, 2015).

2.8.2. The Zero Waste Paradigm

It has been widely agreed that waste disposal and waste minimisation are the first and second generations of resource planning, respectively. Zero waste can hence be thought of as the third generation of resource planning (ZWI, 2015). It has been suggested that to reach Zero Waste, waste prevention must be the new focus instead of simply focusing on management of waste (Doppelt et al, 1999). According to zero waste, the best way to avoid waste is to reuse everything perpetually. In this sense, zero waste aims to wring maximum efficiency from the use of resources (ZWA, 2013).

However, this goal can only be achieved if ‘reuse’ is designed into products right from the start, i.e. attentions need to be paid to the whole lifecycle of products (Green Peace, 2002). This is a different perspective to recycling, where the designers often have the notion of ‘discard’ in mind when designing a product. As a result, current ‘extract, use and discard’ systems squander valuable resources while creating an accumulating debt of damage to land, air, water resources and biodiversity (Doppelt et al, 1999).

Due to the limited literature on zero waste in the construction context, discussions about zero waste will include zero waste studies pertaining to other industries. This ensures

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sufficient knowledge and understanding on this subject matter can be achieved. In particular, zero waste discussions at three levels are made to provide a good understanding of this subject matter. They are discussions of zero waste at: national level, regional level and industry level.

2.8.3. Zero Waste Considerations at a National Level

The concept of zero waste has been accepted and implemented worldwide. Currently at the national level, many countries have specific regulations and strategies to achieve Zero Waste (Connett, 2008; Curran & Williams, 2012). These countries include Italy, Germany and France, Japan, New Zealand and Australia, Canada and the USA. The use of regulations and policies to help achieve zero waste is largely a top-down approach. At the national level, this is perhaps the only way which the government could influence the behaviours of stakeholders and help drive the implementation of the concept (Liss, 2000). Indeed, it has been reported that through governments' effective introductions and controls of environmental policies and waste incentive programmes, many success stories about waste reduction and elimination have emerged around the world (Connett, 2008; Young et al, 2010; Snyman & Vorster, 2011; Phillips et al, 2011 or the GAIA Report - Allen et al, 2012).

In addition, there have been many methods developed to measure, quantify and track zero waste. Whitlock et al (2007) suggest that 'Value Chain Analysis' should be utilised to study the paradigm shift to zero waste. This is a commonly-used tool in waste water treatment and one could provide decision-makers an understanding of drivers affecting zero waste (Whitlock et al, 2007). Similarly, Curran & Williams (2012) argued that a closed-loop model like that used in the ZeroWIN Project might be appropriate for

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eliminating, preventing industrial waste. Curran & Williams' (2012) model is depicted in Figure 3 below.



Figure 3: Close-loop model of the ZeroWIN Project. Source: Curran & Williams (2012)

Perhaps the most convincing model currently available is one proposed by the Department of Environment, Food and Rural Affairs (Defra) in the UK (Phillips et al, 2011). In this framework, a phased development was proposed to achieve zero waste objectives in England by 2014 (Phillips et al, 2011). Since 2007, a zero-waste initiative called 'Zero Waste Places' was implemented in 6 locations with numerous sizes across England. It was reported in 2011 that most case studies met or even exceeded their initial zero waste objectives (Phillips et al, 2011).

Some strategies discussed in Phillips et al (2011) are like those in studies and documents in New Zealand regarding zero waste (e.g., Snow and Dickinson, 2001 or

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Ministry for the Environment, 2010). These similarities may be due to the fact that New Zealand often looks to England as a 'big brother' in terms of policies and goal settings.

Currently, there are issues in New Zealand that have prevented high adoption rates of zero waste in the country (MfE, 2010). There is a severe lack of information regarding size, composition and effects of waste to the New Zealand environment. Without this information, it is difficult for New Zealand to establish baseline objectives for waste minimisation and zero waste.

Also, the geography of New Zealand, where towns and cities are dispersed, means that significant wastage is inherent in the supply chains of all goods and materials in the New Zealand economy. This wastage is in forms of infrastructure and energy, as large infrastructures are required to service small communities. Further, given New Zealand is a small, unreliable and uneconomical market for recycled materials, it does not currently have any economic schemes to encourage adoption of zero waste. The lack of economic schemes may be a crucial factor contributing to the low adoption rate of zero waste in New Zealand (Liss, 2000). Therefore, New Zealand can learn from experience of other countries to establish appropriate strategies to encourage the adoption of zero waste policies in the country.

One significant example is the case of Taiwan. Taiwan's specific waste minimisation approach includes six specific strategies, namely: regulatory amendments, consumption education, financial incentives, technical support, public awareness and stepwise target reviews. It was reported that after 4 years of implementing the zero-waste system (2003-2007), Taiwan's municipal solid waste outputs were reduced by 37%, which far exceeded the original target of 25% reduction. At the same time, Taiwan

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could minimise its industrial waste outputs by 76% (Young et al, 2010). Although this achievement is impressive, one must be cautious when looking at statistics figures like these. This is because although the waste reduction is significant, over the same period a large portion of Taiwan's manufacturing capabilities were moved to China (Michigan State University, 2013). In the researcher's opinion, this movement of industrial and manufacturing capacity between Taiwan and China could skew Taiwan's waste statistics somehow. Despite this, Taiwan is on a proper path to achieve zero waste, with many useful strategies and suggestions have been proposed to help drive the country towards its goal (Young et al, 2010).

Overall, the review of literature pertaining to zero waste at the national level has revealed that the concept is well-perceived and adopted worldwide. But each country needs to be selective of appropriate approaches to take to achieve its successful zero waste goals.

2.8.4. Zero Waste Concept at the Regional Level

Like undertaking at a national level, zero waste has also been widely adopted at regional level. In Los Angeles, 62% of the city's waste is recycled; while San Francisco has established itself as the global leader in waste management, with 77%-80% of the city's waste is recycled and reused (Allen et al, 2012; PBS, 2013). In Italy, it has been reported that even relatively small cities like Novara (population 100,000) near Turin has managed to reach the reduction rate of 70% in very short time - 18 months (Connett, 2008). In Canada, a growing number of municipalities are adopting a Zero Waste as a long-term goal that drives management decisions (AUMA, 2012). For instance, it was reported that people at many municipalities are encouraged to reduce

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waste such as disposable foodware; and instead, reuse, recycle, and compost all such resources whenever applicable (AUMA, 2012). Many other successful cases in implementing zero waste can be found in studies extensively focussing on, or pertaining to, zero waste such as Connett (2008), Zaman & Lehmann (2011), Lehmann (2011) or Allen et al (2012).

In New Zealand, the Opotiki District Council was the first regional council to adopt a Zero Waste policy. The council has 5 Resource Recovery Centres; and which together, have consistently diverted 90% of waste from landfill since 1999 (Knight, 2007). Recently, it has been reported that Auckland Council has adopted zero waste strategy as well. Specifically, Auckland has set a detailed plan for managing and minimising waste, with targets of reducing up to 30% of domestic and in-house council rubbish by 2018 and ultimately, reducing 30% of all waste to landfill by 2027, including C&D waste (Auckland Council, 2012). Although these waste reduction goals of Auckland Council are insignificant in comparison to zero waste set out elsewhere (such as those by Austin Council in Austin, Texas (ARRPM, 2013)), they are ambitious due to Auckland's size in the New Zealand setting. However, based on recent success stories of zero waste implementation in cities worldwide, it is anticipated that Auckland's goals in zero waste could be achievable.

It must be noted that to achieve zero waste, there must be clear guidance as well as incentives to change waste behaviours of all stakeholders and encourage for the uptake of sustainable waste management strategies (Liss, 2000). Since all this comes with a cost to the local authorities, there needs to be holistic and integrated waste management systems in place so the local authorities can make appropriate plans (Zotos et al, 2009).

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Similarly, Zaman & Lehmann (2011) demonstrated that a holistic waste management framework could help cities to work towards “zero waste” objectives. Such a holistic framework must encompass relevant tools, systems, and technologies. Further, the framework must be affordable, practicable, and effective within their local regulations (Zaman & Lehmann, 2011). It was anticipated that this model could be applicable to industrialising Asian and African nations as well as Australia.

Overall, these works all have a major limitation in that they do not offer any specific recommendations about the operational requirements and objectives for having a zero-waste strategy at municipal levels.

Municipal solid waste is comprised of many types of waste; of which C&D waste is composed of about 30%-40% (Wang et al, 2010; Yuan & Shen, 2011). By not having a specific recommendation on how to manage and/or reduce this waste stream is a major weakness of the above-mentioned municipal zero waste studies. It has been shown that having appropriate technology and guiding principles (through regulations and policies) are of utmost importance if a city wants to reach a zero-waste objective (Snyman & Vorster, 2011).

2.8.5. Zero Waste at Industry Level

The review of literature to date has revealed that there is a limited body of knowledge on zero waste at industry level. This lack of studies at this level is perhaps due to the complexity in reporting zero waste at the industry level.

At the national or regional levels, authorities can introduce and pass directives/legislations regarding zero waste. In effect, a national or regional body can

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amalgamate related (or sometimes, distantly related) industries together and establish zero waste strategies without having to worry about how each industry works in order to achieve such strategies.

However, at the industry level, each sector is specific about the way it operates; so it is not possible to amalgamate practices of different sectors together. As an example, the construction sector is comprised of many subsectors (inter alia building, civil, infrastructure) and companies of all sizes operating within or across each sector; each of these subsectors or companies have their own specific ways of working. That makes it difficult for the industry body to implement or impose/enforce a complex strategy such as zero waste to the whole sector using a top-down approach because it may not be able to pinpoint exactly what needs to be done, and how, in order to achieve zero waste for that specific sector.

In the current setting for this research, zero waste studies pertaining to construction are of most interest. However, due to the limited number of zero waste studies in the industry, zero waste cases from other sectors have been included to draw analogous findings for comparisons.

2.8.5.1. Zero Waste Studies in Manufacturing Industry

Some of the earliest studies concerning zero waste at the industry level are Mason et al (2003) and Kumar et al (2005). Although the former is descriptive in nature, it could nevertheless be considered as an impetus for achieving zero waste for universities.

In principle, Kumar et al (2005) agreed with Mason et al (2003) that there needs to be a close interactions and integration approaches between stakeholders. However, the research settings of Kumar et al's (2005) research are different to those of Mason et

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al's (2003) study. Whereas Mason et al (2003) focused on the education sector, Kumar et al (2005) studied the manufacturing industry.

It was found that for the manufacturing industry to achieve zero waste successfully, it must overcome a number of industry-specific barriers and challenges (Kumar et al, 2005). These challenges range from social and environmental considerations; to techno-centric issues around product design, manufacturing and recovery technologies; and finally to end user-related matters such as economics of products and/or users' usage patterns (Kumar et al, 2005). It was further found that the most sustainable recovery option is reusing the whole product because it adheres to the central themes of zero waste (Kumar et al, 2005). However, the some results of this study may not be generalisable and applicable to the construction industry because not every product in construction (e.g. building or building part) is fully reusable as in the case of manufacturing industry. In spite of that drawback, Kumar et al (2005)'s findings related to challenges facing an industry in the quest of, becoming zero waste is nonetheless highly relevant to the construction setting.

Similarly (still in the manufacturing sector), Ball et al (2009) examined challenges in designing and developing a zero carbon manufacturing facility. It was found it is technically viable to achieve a zero carbon objective by smartly integrating flows of material, energy and waste in the manufacturing process (Ball et al, 2009).

Overall, Kumar et al (2005) and Ball et al (2009) have demonstrated that although it is possible to achieve zero waste via technologies alone, careful considerations must be given to this approach because it is an expensive path to achieve zero waste. At the same time, the true long-term success of the techno-centric approach is not fully

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secured, as takes out the equation considerations for human's waste behaviours. Therefore, in the researcher's opinion, a sustainable path towards zero waste must include a combination of technology, metrics and policies.

Recently, a number of major manufacturing companies including Kodak, Ford, GM, Chrysler and 3M all have specific policies and plans for improving their designs in order to allow for easy recycling and reusing of their end products (ZeroWaste, 2011). For instance, it has been reported that as of 2011, more than 90% of the waste generated at GM's worldwide manufacturing facilities was recycled or reused (GM, 2012). Consequently, GM has been continually recognised for its outstanding waste reduction by the U.S. EPA (GM, 2012). This is indeed a significant achievement and one which shows the feasibility and viability of a zero waste policy. Similarly in New Zealand, Fonterra has managed to divert over 75% of waste from its nationwide operations, including the complete removal of dirty plastic from its waste streams (Knight, 2007). In another example, a recent waste audit at Counties Power, which operates between southern Papakura and North Waikato regions, showed that majority of material used by the company could be diverted from landfill. In turn, Counties Power could potentially save up to \$50,000 per annum in waste disposal (Knight, 2007).

2.8.5.2. Zero Waste Studies in Construction Industry

In the construction context, although there has been significant effort in minimising adverse physical effects of the industry on the environment, i.e. solid C&D waste (i.e. Li et al, 2005 or Poon et al, 2010), the 'zero waste' concept still does not seem to get any traction (Osmani, 2011). It has been argued that by reducing C&D waste, construction could potentially experience significant benefits, both in terms of performance and cost savings (Lingard et al, 2010). But this requires every stakeholder in the construction

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supply chain to be proactive in promoting and practicing waste minimisation so that waste minimisation/zero waste schemes can be effective and self-sustaining (Osmani, 2011). Moreover, construction and the government need to collaborate closely to establish a framework to promote and encourage waste reduction as well as associated enforcement methods (Snyman & Vorster, 2011). It has been shown that such a close collaboration between the industry and the government could offer mutual benefits, because while the industry could improve its image of pursuing a better environment, the government gets closer to its national or regional zero waste objectives (Young et al, 2010).

As mentioned earlier, although the number of studies pertaining to zero waste in construction is relatively small in comparison to those in other industries, there is a growing attention given to this issue by construction researchers. In 2002, Alexander (2002) studied the opportunities and resources needed for successful zero waste implementation in the hotel industry and found that in order for it to be implemented, there needs to be a tight integration across the whole sector. It was shown that by having monitoring systems and standards in place, 'green hotel' could be achieved in many countries and locations around the world (Alexander, 2002).

Rubinstein (2012) developed a guideline to achieving the zero C&D waste for builders and contractors. It was anticipated that by following the steps outlined in this study, a safer and waste-free worksite could be the reality in the construction sector (Rubinstein, 2012).

At a technical level, Kinuthia & Nidzam (2011) investigated the opportunity for the construction sector to move towards zero industrial waste by reusing brick dust.

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Through laboratory testing and experiments, Kinuthia & Nidzam (2011) showed that this technology works well and could be used as a material for infrastructure construction. Further, the technology is shown to be sustainable in both economic and environmental terms (Kinuthia & Nidzam, 2011). This study is particularly helpful in convincing the sector to be more sustainable since it has provided a proof that if appropriate effort and technologies are utilised, a zero-waste objective in construction could totally be achieved.

2.8.5.3. Zero Waste Literature Findings

Overall, the body of knowledge regarding zero waste is small, with few technical publications available worldwide. Most of current literature on zero waste tends to describe zero waste rather than offering any real insights into the concept. As such, there is significant knowledge gap that needs to be filled.

In the construction context, there is even smaller portion of literature pertaining to zero waste that is available. This research is one of the first studies worldwide to explore zero waste in construction, aiming to assess economics of zero waste in this context. Findings of this research will enhance the construction industry's understanding of zero waste and its benefits. Further, it is anticipated that this study can help enrich the current general body of knowledge in zero waste.

2.9. C&D Waste: Economic Considerations

For C&D waste minimisation to become a normal practice in construction, there is a requirement for construction companies to pay attention to the environmental, social and economic aspects of their businesses (Lu & Yuan, 2010; Yuan, 2012). This triple-

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bottom line (TBL) approach can offer construction companies significant benefits, including tangible benefits (such as cost reductions) as well as intangible benefits (such as improved public image) (Chung & Lo, 2002; Tam, 2010).

The main consideration for undertaking C&D waste minimisation is its economics. These economic considerations include costs of waste (Peng et al, 2010) and cost of implementation (Shen & Tam, 2002; Kartam et al, 2004; Tam, 2007), as well as the returns on such investments. It has been shown that although it is possible to reuse and recycle most C&D waste using current technologies, waste minimisation in construction still fails to achieve its objectives due to the lack of necessary commercial arguments for its implementation (Ball et al, 2009). Without being shown the commercial imperatives of minimising C&D waste, construction stakeholders are unlikely to change their wasteful attitudes and behaviours to implement C&D waste minimisation strategies.

This finding shows that financial considerations related to waste management are universal and have remained unchanged in the psyche of people in construction. This is the fundamental rationale for undertaking the research reported in this thesis. It is anticipated that based on this study appropriate strategies can be established in the New Zealand construction industry to reduce C&D waste.

Recently, much effort has been made to evaluate the economics of C&D waste management and minimisation. For instance, Yahya & Boussabaine (2006) proposed a framework to assess eco-costs of construction waste programmes while Begum et al (2006) provided useful cost-benefit analysis model to evaluate economics performance of Malaysian construction's waste minimisation. Similarly, Tam & Tam (2008) provided

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a step-wise incentive scheme to evaluate the economics of C&D waste strategies. This model has proven to be effective in encouraging C&D waste minimisation practices in Hong Kong (Tam & Tam, 2008).

As money is a key driver in a waste minimisation strategy, there needs to be instruments to enhance its effectiveness. These instruments can be ‘push’ factors such as industry-focused legislations and/or performance standards. Alternatively, they can be ‘pull’ factors such as incentives and subsidies.

In the ‘push’ category, it has been shown that C&D waste-specific landfill and levy charges help reduce levels of waste generated significantly (Sealey et al, 2001; MfE, 2009; Yu et al, 2013). Actions in the ‘push’ category are often mandated by governance bodies such as the government or industry bodies. However, these organisations can only implement a strategy if they see values in doing so; and often such values predominantly include economic considerations.

By contrast, in the ‘pull’ category it has been shown that with right incentive schemes, significant volumes of C&D waste can be eliminated (Tam & Tam, 2008). Unlike in the ‘push’ category, actions to introduce incentives or penalties can be undertaken by anyone in the supply chain. For example, in a project the client could introduce penalties to cut cost and to ensure contractors deliver projects to the required standards. At the same time, the client may offer incentives to motivate contractors to deliver project goals quickly or timely. In return, the contractor may use penalties to pass on the cost to their sub-contractors and suppliers. Alternatively, the contractor may pass on a fraction of incentives received to their sub-contractors and suppliers to motivate them or to establish a working relationship with their sub-contractors. In

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construction, often only the costs associated with a C&D waste management strategy is guaranteed to be passed down the supply chain line, as companies look to minimise their risks. While on the other hand the financial benefits may be introduced for a specific reason and as the client side sees fit. Currently there is a lack of incentive and penalty schemes in New Zealand to encourage the construction industry to manage and minimise its waste outputs.

Being a major waste generator in New Zealand, the construction industry can do more to minimise waste; and in turns, be a good promoter of waste minimisation. It is anticipated that based on the results of this research, appropriate pathways can be formulated to guide and ensure the New Zealand construction industry meet its sustainability objectives.

2.10. Knowledge Gaps

Through the review of the literature, a few knowledge gaps have been identified.

2.10.1. Definition of C&D waste in New Zealand

As mentioned in Section 1.1, currently there is a lack of definitions of C&D waste worldwide. This lack of definition for C&D waste has many implications in New Zealand. First, the lack of a uniform C&D waste definition in New Zealand contributes to the lack of understanding of C&D waste compositions. Without a clear idea of C&D waste compositions, it is difficult to formulate strategies to address C&D waste streams.

Second, the lack of C&D waste definitions means that waste may be classified differently between locations, leading to varying waste minimisation practices. The

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result is C&D waste management/minimisation efforts at one location may not be applicable to other locations, thus exacerbating the C&D waste problems further.

To overcome this challenge, this research introduced a definition of C&D waste in Section 1.2. This definition of C&D waste was specific for this study and was introduced to avoid any potential ambiguity in, and associated with, all work reported in this thesis. Although the definition of C&D waste offered here is specific to this study, it is anticipated that it contributes to the current knowledge in C&D waste minimisation.

2.10.2. Motivators for C&D waste minimisation

Through reviewing the literature, it can be argued that without a good understanding of the factors affecting C&D waste minimisation, it is difficult to develop appropriate strategies that could be adopted by all construction stakeholders. In New Zealand, currently there is no existing literature that specifies the motivators that drive C&D waste minimisation strategies. This is a missed opportunity and one which this research could partially address.

Based on the existing literature and the researcher's experience in the New Zealand construction industry, it could be contended that a lack of incentive and penalty schemes in New Zealand has discouraged construction to minimise its C&D waste. This is purely a speculation and will require further researches to investigate it. In this study, this speculation is not tested, as it is outside the scope of this research.

It can also be contended that a collaborative working environment is a key motivator in C&D waste minimisation. It has been shown in the literature that to successfully implement a C&D waste minimisation strategy, there is a requirement that construction stakeholders must work together collaboratively. However, currently there is a lack of a

collaborative framework in New Zealand construction. This lack of collaboration in New Zealand is due to the industry's fragmentation. As such, there is an urgent need to investigate the relationship between company sizes and its willingness to participate in collaborative framework to reduce C&D waste. This understanding can help New Zealand construction to develop appropriate strategies for C&D waste minimisation.

2.10.3. Economic evaluation of C&D waste minimisation

The literature review demonstrates that currently there is no existing economic framework for the evaluation of the economics of C&D waste minimisation strategies in New Zealand construction. In a way, this knowledge gap is a direct result of the first knowledge gap. However, it is perhaps as important as, if not more important than, the former. This is because the lack of economic evaluation methods to assess the economics of C&D waste minimisation strategies is the main reason construction continues to do nothing about its C&D waste issues.

Further, the literature review indicates that there are currently a number of economic models concerning C&D waste management and minimisation (e.g. Covec, 2007; Tam & Tam, 2008; Jain, 2012; Coelho & de Brito, 2012; Dajadian & Koch, 2014; Fadiya et al, 2014; Abdelhamid, 2014; Marzouk & Azab, 2014; Wang et al, 2014). However, these models could not sufficiently address a key issue: how to identify 1) the optimal C&D waste minimisation strategies and 2) the optimal C&D waste reduction rate. This is a major knowledge gap in the current understanding of C&D waste minimisation economics which needs to be addressed. This is indeed the fundamental rationale for the research reported in this thesis.

2.11. Conclusion

This chapter has discussed in detail C&D waste and its related areas. In particular, topics that have been touched upon in this chapter include Green Construction, Sustainable Construction, C&D Waste Management, C&D Waste Minimisation and Zero Waste. Green Construction and Sustainable Construction are wide-ranging research topics; and they have provided sufficient background to the study reported in this thesis. This is mainly due to these concepts' broad focuses on minimising adverse environmental effects of construction.

Overall, there have been many techniques and methods proposed in the literature regarding C&D waste minimisation. However, it has been found through the literature review that to ensure the long-term viability of any C&D waste minimisation strategies, the construction industry must be convinced of the economics of such strategies. This is because money considerations are still a key consideration in construction thinking. Therefore, the strategies need to demonstrate commercial imperatives for them to be implemented.

Zero waste is the final topic discussed in this chapter. In a way, zero waste is the goal of waste minimisation. It was shown thorough the review of literature that this topic is still in its infancy, with limited publications dedicated to this area of research. With recycling and reusing waste as its focus, the 'zero waste' concept indeed suits the purpose of this study well. Due to the limited literature in the body of knowledge of zero waste, there is no study to date that investigates the economics of implementing it. This

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is indeed a gap in knowledge that needs to be filled; and this study is in an appropriate position to facilitate it.

To understand the economics of C&D waste minimisation strategies, there is an urgent need to understand methods used in the economic evaluation process. This area of knowledge will be discussed in Chapter 3. Discussions of economic evaluation methods will provide a good understanding of the techniques available and their suitability for this study.

**CHAPTER 3 - AN OVERVIEW OF ECONOMIC EVALUATION
METHODS**

CHAPTER 3 – ECONOMIC EVALUATION METHOD OVERVIEW

Chapter 2 has provided an understanding of issues related to C&D waste and C&D waste minimisation. It was found in Chapter 2 that there is a need to evaluate the economics of C&D waste minimisation strategies in New Zealand. To this end, there is an urgent need to understand economic evaluation techniques that are available and their suitability to this research. This is the purpose of this chapter.

3.1. Introduction

Economic evaluation is a process involves establishing, modelling, analysing and recommending courses of action to help achieve an economic objective. It is a complex process in which critical factors such as costs, risks and returns are thoroughly analysed and evaluated. Investment decisions are then made based on the economic analysis (Dimitrakopoulos and Abdel Sabour 2007; Steffen et al. 2008; Topal 2008; Card 2009). It has been observed that by considering various alternative options, economic evaluations can help decision makers add significant values to a strategy for a relatively small cost (Mackenzie and Cusworth, 2006).

This chapter provides readers a general understanding of economic evaluation methods. Subsequently appropriate economic evaluation methods for this research will be chosen in section 3.9.

3.2. Nature of this Research

The question of whether this study should take a macroeconomic approach or a microeconomic approach is one which the researcher has been grappled with since the beginning of this research journey.

On the one hand, to ensure a waste minimisation strategy for the construction industry to be successful, this research needs to take a big-picture view of the issues related to C&D waste and C&D waste minimisation in New Zealand construction in order to develop a framework to evaluate its economics accordingly. This means a macroeconomic vision is required.

On the other hand, since the New Zealand construction industry is made up mostly of small companies with limited resources. As a result, large-scale or industry-wide C&D waste minimisation programmes are often the main deterrent to small construction companies, given the relatively high costs associated with such implementations. This means only a selected few companies with resources can afford to have comprehensive C&D waste management programmes.

Besides due to the fragmented nature of the New Zealand construction industry, the uptake C&D waste minimisation largely depends on the willingness of construction companies. It is therefore difficult to implement such programme industry-wide without buy-ins from the construction companies.

Often, the implementation a C&D waste minimisation strategy is on a case-by-case basis and is highly dependent on the specific nature and requirements of each project.

Considering the above reasons, the researcher concluded that it is appropriate to consider this research at the microeconomic level.

3.3 Economic Evaluation Method Overview

All available economic evaluation tools originate from the financial industry, where they are used extensively to value investments and their respective risks and returns (Maybee, 2010).

There are many economic evaluation methods available and their complexity depends on the problems at hand. Highly complex economic evaluation tools include econometrics and complex systems while simple economic evaluation techniques are payback period and break-even analyses. In this study, the problem of evaluating the economics of zero waste in the building construction context means that the chosen economic evaluation tool must satisfy two fundamental conditions.

First, the economic evaluation framework developed in this research must be user-friendly. The New Zealand building industry is made up mostly of small- to-medium size companies who have different aims and objectives. Due to their limited size and resources, these companies often require seeing values in waste minimisation before committing their resources to take part in such a strategy. This requirement means that the framework developed in this research must be easy to use. This allows companies to adapt the framework to suit their needs

Second, as shown in Chapter 2, C&D waste consists of many waste streams. And there are many interacting factors that may affect a waste minimisation strategy. As a result, the framework developed in this research should be flexible enough to evaluate the economics of waste minimisation strategies for diverse types of C&D waste streams under various situations. This means the economic evaluation tool must be able to

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process new information as they emerge and model it without major modification and tweaking of existing economic models.

The two fundamental requirements above mean that highly complex methods such as econometrics and complex systems modelling are unsuitable for this research. This is because both methods are highly specialised and require a high degree of technical capability in economic theory to operate. Further, as additional information emerges, these methods are incapable of processing it without the involvement of major remodelling work.

Therefore, due to the specific requirement of this study and the limitation posed by techniques such as econometrics and systems modelling, this research will focus on more traditional economic evaluation techniques instead.

However, this chapter only discusses five traditional economic evaluation categories.

This is to ensure the scope of the study remains manageable. These categories are:

- Financial Analysis (FA)
- Benefit-Cost Analysis (BCA)
- Economic impact analysis (EIA)
- Cost Effectiveness Analysis (CEA)
- Fiscal Impact Analysis (FIA)

Economic evaluation techniques in these five categories will be refined further to choose the most appropriate evaluation methods for this research.

3.3. Financial Analysis (FA)

Financial analysis is an umbrella term comprising various techniques and methods used to evaluate projects or strategies. Common economic evaluation tools in this category include, but not limited to, Payback Period, Internal Rate of Return, Net Present Value and Real Options.

This section will discuss these methods in detail to provide a good understanding of their strengths and weaknesses. Subsequently, arguments will be made regarding the most appropriate methods to be used in this study.

3.3.1. Payback Period (PBP)

Payback Period (PBP) is ‘the time required for the capital outlay to be repaid’. In other words, it is the estimated time taken for the project to produce profits equals to the initial capital.

However, this approach is theoretically flawed due to several shortcomings. First, PBP is not a discounting technique, as it does not account for the time value of money or the opportunity cost (Topal, 2008). Second, PBP only considers a relatively fixed time horizon on investment; and this may cause biases towards investments with long-term benefits (Abdel Sabour & Poulin, 2006). Despite being a commonly used evaluation techniques, PBP could provide ambiguous results in situations where the sign of the cash flows switch between positive and negative more than once (Maybee 2010). While PBP is used as a “sanity check”, the method does not provide a good platform to rank multiple alternatives (Lee and Strang, 2003a).

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Recently, improvements to PBP have been made. Discounted PBP (DPBP) is a reformulated evaluation technique that is Net Present Value (NPV)-compatible and capable of producing results that recognise the entire project cash flow (Hajdasinski, 2012). The advantage of this approach over the traditional PBP is its ability to convey informative facts for investment decision making purposes. The reformulation also provides a means of ranking mutually exclusive alternatives through the evaluation of projects based on their differential cash flows (Maybee, 2010).

Recently another method has been introduced by Alesii (2006). In this novel approach, PBP is combined with Internal Rate of Return (IRR) to reduce their weaknesses (Alesii, 2006). Overall, Alesii's (2006) method could provide results that are consistent with the NPV-based techniques.

3.3.2. Internal Rate of Return (IRR)

Internal rate of return (IRR) is another evaluation technique often used in financial analysis. IRR is often used to measure and compare the profitability of investments: the higher the IRR of a project, the more desirable it is.

IRR is the rate at which the net present value of inflow cash equals the present value of outflow cash. IRR could offer valuable insight into the yielding rate or return on investment of a project. This technique is very widely used. For example, more than half of mining companies in 1994 used IRR for project valuation while 40% using net present value (NPV) (Hajdasinski, 2012).

3.3.3. Net Present Value (NPV)

NPV is arguably the most widely used economic evaluation technique for decades (Dimitrakopoulos & Sabour, 2007; Topal, 2008). It is a standard evaluation technique in many industries.

In this method, all future cash flows are estimated and discounted to the present day's value using an appropriate discount rate. NPV is the sum of all discounted future cash flows. NPV method is used for dual purpose. First, NPV is used as an economic evaluation tool to place a value on a project. At the same time, NPV is used as a decision-making tool to guide managers and decision makers to choose between alternatives, i.e. a project with highest NPV values (among alternatives) is accepted.

In NPV method, discount rates have significant effect on the value of a project: a small change in the discount rate can cause a large change in NPV values. Further, choosing the appropriate discount rate is probably the most difficult and uncertain part of NPV methodology. As a result, NPV's reliability is often questioned (Xie, 2010). It is often found that NPV undervalues projects because it 1) lacks the ability to account for different types of uncertainties and risks in such projects and 2) fails to price flexibility inherently exists in the management of risky assets (Topal, 2008). By including time-value-of-money and risk discounting in one single discount rate, the single-rate NPV approach is inherently biased against high-margin/long-life assets with large capital requirements and a bias towards low-margin/short-life assets with low capital investment (Lai & Stange, 2009b). Therefore, variable discount rates should be used in NPV calculations (Blais et al, 2007; Pietersz, 2011). Another drawback of NPV as an evaluation tool is its implicit assumption of the certainty regarding future cash flow over

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the life of the project (Fox, 2008). Often, effects of cyclical fluctuation capital and operating costs are ignored in NPV method. Even though smoothing these can make it easy for NPV calculations, these factors indeed change constantly and will affect the project value long term (Martinez, 2009).

The final pitfall of NPV is its built-in assumption that a manager is passive in decision-making (Dimitrakopoulos & Sabour, 2007). That is managers are 'victims of circumstances' with no ability to affect positive improvements in cash flows et cetera during the operation of the asset. This is in contrast to reality, where managers have significant flexibility (Maybee, 2010). And once the project starts, the manager have discretions concerning all aspects of the project, from design to sourcing of materials to production methods (Martinez, 2009). However, the consensus for making decisions based on this technique is to undertake the investments with positive NPVs and reject those with negative NPVs (Sabour & Poulin, 2006). With immediate acceptance/rejection, NPV ignores the value of options such as deference/abandonment or expansion/contraction/shut down of the investment. Therefore, it must be careful when using and interpreting results of NPV evaluation method (Fox, 2008; Pietersz, 2011).

3.3.4. Real Options (RO)

RO is considered an improvement of NPV. It is an adoption of the financial industry's Options Theory to real-life projects in construction, mining or oil & gas industries (Borison, 2003). Like its financial counterpart, a real option is the right, but not the obligation, to undertake business decisions. It has mainly used to evaluate investments with significant uncertainty because under uncertain conditions, RO performs better

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than the conventional NPV due to the inclusion of management flexibility (Dimitrakopoulos, 2010; Birge, 2012). This managerial flexibility provides opportunities to maximise the upside potential while limiting the downside losses.

Construction investments, like other real-life investments, have three important characteristics. First, investment is partially or completely irreversible. This means once project investments are made, their capital costs become totally or partially sunk. Second, there is uncertainty over the future return from the investment. It is difficult, if not impossible, to predict accurately the levels of tenancy in any commercial or building projects at the commencement of the project. Finally, the management have a degree of flexibility in timing the investment. In any construction company, the management can choose if, and when, to invest in a project that meets the company objectives. However, NPV cannot incorporate these three characteristics (Yang & Blyth 2007). RO adjusts risk within cash flows while NPV adjusts risk by aggregating cash flows. This small difference allows RO to differentiate assets according to their unique risk characteristics, while the conventional NPV approach cannot (Samis et al, 2006). Another advantage of RO over NPV is the way it handles discount rates: while NPV uses risk-adjusted discount rate, RO uses a risk-free rate or lending rate when risk-free rate is not available (Smith & McCardle, 1996; Walls, 2004; Martinez, 2009). Therefore, RO yields higher values than conventional NPV method. Although the difference in risk adjustment between the NPV and RO appears to be a nuance, RO allows management to use market information to determine value of risks (Samis et al, 2007). In the absence of flexibility, the only difference between NPV and RO is the manner of accounting for the effect of cash flow uncertainty on asset value. It has been recommended against scraping altogether the traditional NPV method, as the

advantages of RO over NPV are not fully proven (Dimitrakopoulos & Sabour, 2007). Nonetheless, RO has become a useful tool for decision-making (Barman & Nash, 2007).

3.3.5. FA method used in this research

In the FA methodology, the PBP technique does not account for time value of money. This is a major drawback because a waste minimisation strategy can take a long time to reap the benefits. And PBP's inability to account for time value of the money spent on such a strategy may limit the economic understanding of such a strategy significantly.

Similarly, due to an uncertainty around the benefits or returns associated with a waste minimisation strategy, it can be difficult to project or estimate the expected rate of return (IRR) for such a strategy. In practice, if the required IRR is too high, companies may be shied away from such an implementation due to their fear of not achieving it. But on the other hand, if the IRR is too low, companies may not be so keen to invest in a risky strategy consisting of high upfront cost with uncertain and low returns.

As a relatively new economic evaluation technique, real options (RO) has not been widely used and understood by the construction industry. This is perhaps due to it being relatively more complex than NPV in calculating the final values. According to the first fundamental requirement for economic evaluation framework set out in Section 3.2 above, RO is not suitable for this research.

NPV is chosen method as a preferred economic evaluation method in this research. NPV is sufficient in this study because it is a widely-used and well-understood technique by construction professionals. This allows the study to convey its concept and findings to a wide range of audience in the New Zealand construction industry.

3.4. Economic Impact Analysis (EIA)

EIA is an economic evaluation technique that focuses on providing the estimated economic contributions or benefits of a strategy to the surrounding communities where the strategy is applicable as well as the general economies (see, for example, Bellu & Pansini, 2009; Impact Datasource, 2009; PwC, 2012; Loftsgaarden & Derczo, 2013). The economic impacts can be broadly divided into 3 categories: direct impacts, indirect impacts and induced impacts (Weisbrod & Weisbrod, 1997; Knapp, 2001).

Direct impacts are the direct results of the strategy under study such as the number of jobs created as a result of the strategy implementation or amount of salaries and wages generated by the strategy implementation. Alternatively, direct impacts can be measured by business outputs (such as volumes of sales) or added value (such as taxes or gross regional product).

Unlike direct impacts, indirect impacts are ‘second round’ impacts that would only happen if the strategy were implemented. Indirect impacts can be measured by the number of jobs created in the supply chain i.e. those created by suppliers and subcontractors to meet strategy’s demand. It can also be measured through business outputs such as amount of income which is generated from suppliers’ purchasing goods and services or the added values such as taxes as a result of the purchase of goods and services by suppliers.

Finally, induced impacts are the result of people spending their disposable incomes at the household level. These disposable incomes can be wages and salaries earned by people.

The sum of these 3 categories of economic impacts is the ‘total economic impact’ of a strategy. The outputs of an EIA are typically used to demonstrate the economic importance of a strategy to a range of stakeholders including government, community and organisations. Therefore, the economic impact analysis can be powerful tool to build support from stakeholders (EPA, 2010; PwC, 2012)

In term of methods used in the EIA, there are 2 types: the input-output model (I/O model) and economic simulations. The I/O model often relies on inter-industry data to determine the economic impacts of the strategy on the regional economy. Some examples of I/O models used for economic impact analyses are IMPLAN and MITEIM (Mulkey & Hodges, 2012). On the other hand, economic simulations often rely on econometric and general equilibrium models to determine the economic impacts of the strategy. As a result, this type of EIA models is complex and requires expert knowledge in econometrics. In addition, economic simulations often require significant data. One example of economic simulation type is the REMI Model (REMI, 2015). Between the 2 EIA methods, the I/O model is more widely used.

As a macroeconomic evaluation tool, EIA may not be applicable to this research. A detailed evaluation of economic evaluation tools in section 3.8 will provide further insight into this matter.

3.5. Benefit-Cost Analysis (BCA)

BCA is an economic evaluation method aiming to systematically and fairly estimate the strengths and weaknesses of competing options or strategies (AmStat, 2006). In BCA,

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the benefits and costs of the proposed strategies is determined and quantified into dollar values. These monetary terms are often adjusted for the time value of money (Europa, 2008). The economic efficiency of each strategy is compared against each other using a benefit-to-cost ratio. Based on the benefit-cost ratio of each option, the decision-maker can choose a strategy that best suits their requirements. BCA provides decision makers with a consistent and effective way to assess the merits of alternative strategies to make sound decisions

BCA can be used either as a stand-alone evaluation technique or in conjunction with other economic evaluation methods such as cost-effectiveness analysis, risk-benefit analysis, economic impact analysis and fiscal impact analysis. Due to its versatility, BCA is widely used by both the government and private sectors (OECD, 2006; Cellini & Kee, 2010). In New Zealand, BCA is the standard economic evaluation technique employed by the New Zealand Transport Agency (NZTA). Recently NZTA has published an economic evaluation manual with BCA as the central evaluation theme (NZTA, 2013). All transport-related publications from the Agency have used BCA as the standard measure (e.g. Leung et al., 2013; Opus, 2015).

BCA has many advantages, including the ability to provide well-educated estimates of the best option among alternatives. However, due to the difficulty of estimating all costs and benefits accurately, careful and thorough considerations are recommended when using BCA results (OECD, 2006).

As a flexible economic evaluation tool, BCA may be suitable for this research. A detailed evaluation of economic evaluation tools in section 3.8 will provide further insight into this matter.

3.6. Cost Effectiveness Analysis (CEA)

Like BCA, CEA is an economic evaluation technique that relates the costs of a programme to its key outcomes or benefits (Cellini & Kee, 2010). CEA works by benchmarking the cost of each strategy against the unit of effectiveness (or output). A programme is considered 'cost-effective' if it can present a bargain in relation to its competitors for the same amount of resources (Pinkerton et al., 2002). In this sense, CEA is best suited for comparison between alternatives that can deliver similar benefits. CEA is often used in lieu of BCA when the benefits are difficult to evaluate, e.g. safety, health or perceptions (WHO, 2003; Jamison, 2006; Phillips, 2009).

However, due to the difficulty to estimate 'effectiveness', it has been recommended that CEA should be used in conjunction with other economic evaluation techniques such as sensitivity analysis, BCA or EIA (Phillips, 2009; Cellini & Kee, 2010; Europa. 2014).

As a flexible economic evaluation tool, CEA may be suitable in this study. A detailed evaluation of economic evaluation tools in section 3.8 will provide further insight into this matter.

3.7. Fiscal Impact Analysis (FIA)

Fiscal impact analysis is a tool often used by the local government to compare the costs incurred in the developments of policies, strategies or projects against the revenues generated from such developments (Atlanta, 2009). It is similar to the cash flow analysis used by the private sector since it projects the public sector's cash flows resulted from the proposed developments. A FIA should reflect the strategy's capital

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costs, operating expenses and revenue in detail (Kotval & Mullin, 2006). This is in contrast to an Economic Impact Analysis, as the latter only evaluates direct and indirect impacts (such as new jobs, real disposable income and consumer spending) on the overall economy.

The advantage of FIA is the technique can provide officials with detailed forecast of a strategy or project. However, its drawback is that it requires significant data to obtain refined estimates (Harrison & French, 2000, SmartGrowth America, 2013).

As a macroeconomic evaluation tool, FIA may not be applicable to this research. A detailed evaluation of economic evaluation tools in section 3.8 will provide further insight into this matter.

3.8. Chosen Economic Evaluation Methods in this Study

3.8.1. Evaluation of Methods

All four categories of economic evaluation tools described in this chapter are useful. Further, they all have their respective strengths and weaknesses. As a result, careful considerations are needed when choosing them for economic evaluations.

In this study, the chosen economic evaluation tools must meet two fundamental criteria set out in Section 3.2. As a result, there is a need to evaluate the economic evaluation techniques to ensure they are suitable for the context of this research and in accordance with the above fundamental criteria.

For this purpose, several criteria are introduced to help the evaluation. These criteria are unique to this research for two reasons.

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First, they focus on the research problems of this study - to addressing the economics of C&D waste management. This criterion is important because it ensures the chosen economic evaluation methods are suitable to address the research context.

Second, the criteria introduced here closely follow the theme of the first fundamental criterion set in Section 3.2. This ensures the chosen economic evaluation methods meet the research requirements of this study.

These criteria are:

- The ability of the economic evaluation tool to consider economics of C&D waste management strategies at macro level
- The ability of the economic evaluation tool to consider economics of C&D waste management strategies at micro level
- The ability of the economic evaluation tool to compare economic efficiencies of C&D waste management strategies
- The ability of the economic evaluation tool to assess economic viability of each strategy
- The ability of the economic evaluation tool to provide indications to achieve economic objectives

Table 3 below summarises the comparison of economic evaluation methods.

Table 3: Comparison of Economic Evaluation Methods

Criterion	NPV	EIA	BCA	CEA	FIA
Ability to consider economics of C&D waste management strategies at macro level	✓	✓	✓	✓	✓
Ability to consider economics of C&D waste management strategies at micro level	✓	x	✓	✓	x
Ability to compare economic efficiencies of C&D waste management strategies	✓	✓	✓	✓	x
Ability to assess economic viability of each strategy	✓	✓	✓	✓	✓
Ability to provide indications to achieve economic objectives	✓	✓	✓	✓	x

3.8.2. Choice of Economic Evaluation Methods for this Research

It can be seen from the evaluation in Table 2 that EIA and FIA are mainly applicable to macroeconomic evaluations of strategies (also as shown in their descriptions in Sections 3.2 and 3.6, respectively). This is in contrast with the other evaluation methodologies, where they can be applied to the evaluation of strategies at both microeconomic and macroeconomic levels. As argued in Section 3.7, the problem presented in this research is microeconomic in nature. This means EIA and FIA are not appropriate methods for this research.

This means the three economic evaluation methods that meet all criteria set by this study and will be employed in this study are NPV, BCA and CEA.

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NPV is used wherever applicable to account for the time value of money. Due to its versatility, NPV will allow the framework to be used widely in the New Zealand construction industry.

BCA is used to compare the economic efficiency of C&D waste minimisation strategies. It is anticipated that this information can be used to formulate appropriate strategies to address C&D waste.

Finally, CEA is used to compare the cost efficiency C&D waste management strategies. By using CEA in conjunction with BCA, the research can provide sufficiently detailed information regarding the most economically optimal C&D waste minimisation strategies.

3.9. C&D Waste Economic Models – A Comparison

To ensure the economic evaluation framework developed above is unique, it is necessary to compare this framework with those in other studies. Recently, Dajadian & Koch (2014) discussed several costing models for C&D waste management. These models were basic and did not consider the values gained from C&D waste management. This is unlike the economic framework developed in this thesis, where both costs and benefits associated with C&D waste minimisation are taken into account and evaluated accordingly.

Similarly, Fadiya et al (2014) introduced a model to estimate the cost of construction waste. Fadiya et al's (2014) model has several similarities to the costing calculations in the framework developed in this research, including those for unit cost calculations and cost of waste. However, unlike the costing model in this study, Fadiya et al's (2014)

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cost of waste did not consider cost of design-out-waste, cost of waste policy, cost of waste collection, cost of recycling waste, cost of reusing waste and cost of energy. This was Fadiya et al's (2014) drawback and has been addressed by this research.

Taking a distinct perspective, Tam & Tam (2008) focused on the benefit side of C&D waste minimisation. In their study, Tam & Tam's (2008) study focused on incentive schemes as the main mechanisms to motivate C&D waste minimisation. Tam & Tam's (2008) work was relevant to this study. In fact, it provided the researcher some basic steps in formulating calculations for economic evaluation purposes. As a result, it was used a reference in the development of the economic evaluation framework in this study. The weakness of Tam & Tam's (2008) work is its inability to provide an objective evaluation of waste minimisation strategies, as it did not consider the costs associated with such strategies.

In his work, Jain (2012) offered a robust economic framework taking into consideration both costs and benefits of C& waste management. Jain's (2012) approach is different to other studies discussed in this section thus far. In fact, this approach is like one offered in this study. However, unlike this study, Jain's (2012) is descriptive in nature, as it only outlined the main cost and benefit components without showing their detailed calculations. Further, Jain's (2012) costing model did not consider three key components: the cost of design-out-waste, the cost of waste policy and the cost of energy. Jain's (2012) drawbacks have been largely addressed in this study.

In 2007, Covec Limited was commissioned by the Ministry for the Environment to conduct a cost – benefit analysis of recycling waste in New Zealand. On the surface, Covec's (2007) study and the current research appear to take a similar path. However,

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Covec's (2007) study covered a wide range of waste, including household waste, C&D waste and industrial waste. Further, Covec's (2007) underlying conceptual framework is much different to that of this study's. Whereas the benefit component in Covec's (2007) covered three aspects (landfill costs, collection for landfill and 'other'), the benefit component of this study cover four areas: cost saving of materials, cost savings on waste generation, cost saving from reusing and recycling and revenue from selling construction recycled materials. Similarly, the cost component of Covec's (2007) study only covered two areas (collection and sorting) whereas the cost component of this study is much more comprehensive, covering eight areas: design-out-waste, waste policy, waste collection, waste disposal, recycling, reusing waste, energy and waste material. Further, the calculations in Covec's (2007) were descriptive in nature, making it difficult to understand derivations of costs and benefits. Like all studies above, all of Covec's (2007) weaknesses have been rectified in this research.

Aside from similar studies to this research, there are a number of studies that are useful for the development of economic evaluation this research. They include the work of Coelho & de Brito (2012), Abdelhamid (2014), Marzouk & Azab (2014), Wang et al (2014). Although these studies did not address the economics of C&D waste minimisation, collectively they have provided the researcher an in-depth understanding of issues and factors affecting C&D waste minimisation strategies.

3.10. Conclusion

This chapter has reviewed commonly-used and readily-available economic evaluation methods. Subsequently, the chapter evaluates their suitability in the problem being

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investigated by this research, i.e. evaluation of C&D waste minimisation strategies in New Zealand.

It has been found that economic evaluation techniques that will be employed in this study are Net Present Value (NPV), Benefit-Cost Analysis (BCA); and Cost Efficiency Analysis (CEA). These methods are suitable for this research, as they meet the two fundamental research requirements for this study.

Chapter 2 and Chapter 3 have provided a good understanding of C&D waste issues and methods to evaluate economics of C&D waste minimisation strategies.

The next chapter proceeds to identify the research methodology that will be employed in this research.

CHAPTER 4 - RESEARCH METHODOLOGY

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Chapter 2 reviewed literature pertaining to practices around C&D waste minimisation and zero waste. As a result of this literature review, a number of knowledge gaps were identified. To address these knowledge gaps, this study requires an appropriate research methodology. This chapter will discuss the research strategy to be employed in this research.

4.1. Introduction

The word 'methodology' means the 'theory of undertaking an activity' (Novikov & Novikov, 2013). It originates from the word 'method' (meaning a 'systematic procedure or technique of doing something') and the suffix '-ology' (indicating 'science or study') (Oxford Dictionaries, 2014). Research methodology is thus the theory of undertaking research. It is a way to systematically solve a research problem (Kothari, 2004; Rajasekar et al, 2006).

Research methodology is important because it provides a research necessary scientific and philosophical background (Adams et al, 2007; Jonker & Pennink, 2010). A research methodology is useful, as it allows the researcher to understand knowledge and constraints placed upon their concept of 'knowledge'. Further, a research methodology provides the researcher with an understanding that although there are diverse ways that knowledge can be created, only knowledge generated in a methodical and justifiable way is accepted (Adams et al, 2007; Jonker & Pennink, 2010). Therefore, research methodology needs to be carefully identified, designed and applied in any research.

4.2. Problem Analysis

The problem being investigated in this research is specific:

- Currently there is a lack of an understanding of factors affecting C&D waste minimisation strategies in New Zealand
- Currently there is a lack of an established economic evaluation framework to evaluate and establish optimal waste minimisation strategies for building projects

To resolve the above problem, it is necessary to identify and understand the factors that may have significant effects on C&D waste minimisation strategies in New Zealand. At the same time, it is important to understand the economic impacts of these factors on C&D waste minimisation strategies. The second understanding will in turns allow for an establishment of the most optimal C&D waste minimisation strategy in building projects.

These two requirements mean that there is a need for this research to establish an economic framework to evaluate the economics of C&D waste minimisation strategies in the New Zealand building industry.

4.3. Research Aim

The aim of this research is to evaluate the economics of a zero-waste strategy in the New Zealand context and to identify the most economically optimal waste minimisation strategy in New Zealand construction projects.

4.4. Philosophical Foundation of Research Methodology

There are four branches of philosophy: metaphysics, epistemology, ethics and logic (Shakantu, 2004). However, only the first two branches are relevant to research methodology (Chia, 2002; Babbie, 2007). It has been argued that ontological assumptions are the precursor of epistemological assumptions. In turns, epistemological assumptions are the precursor of methodological considerations (Cohen et al, 2007). In this sense, the researcher's worldview can have significant influence on their search for knowledge. In this study, the philosophical foundation of research methodology is established as per Cohen et al (2007). This means discussions about the ontology of a study are offered first; followed by the epistemology.

4.4.1. Ontology

Ontology is the study of 'being' (Cocchiarella, 2007; Gray, 2009). The study of ontology revolves around 2 opposing types: Heraclitean ontology ('becoming') and Parmenidean ontology ('being'). Their differences are summarised in Table 4.

Between these 2 ontological traditions, Parmenidean ontology is more popular in Western philosophy than its counterpart (Gray, 2009). This is despite evidence of recent interests in Heraclitean thinking (Chia, 2002; Shakantu, 2004).

Table 4: Heraclitean Ontology vs. Parmenidean Ontology

Type	Heraclitean Ontology	Parmenidean Ontology
View on Reality	Dynamic and ever-changing	Permanent and composed of entities with identifiable properties and characteristics
View on Knowledge	Relative and ever-changing	Independent of the researcher and can be represented by symbols, descriptions and concepts
Knowledge Generation Process	Requires subjective approaches, meaning the researcher is part of the knowledge generation process, i.e. processual	Requires objective approaches, oriented towards outcomes

Source: Inter alia, Newman (2000); Chia (2002); Gray (2004); Gray (2009); Paparone (2010)

This study aims to evaluate the economics of C&D waste minimisation strategies in New Zealand construction. This investigation has two characteristics. First, the research is based on the concept ‘C&D waste minimisation’. This is a well-established concept with a rich and comprehensive body of literature. It therefore has clear objectives and guiding principles. Working under this general concept ensures the objectivity of this study.

Second, this research should provide a good understanding of economics of C&D waste minimisation in New Zealand through an economic evaluation framework. This economic framework consists of mathematical models with associated mathematical assumptions to represent the inner working of the evaluation process of C&D waste minimisation strategies. The use of mathematical-based economic models will ensure the results to be represented in a clear, concise and quantifiable manner. It is further anticipated that the study provides an impetus for further investigations in New Zealand.

From an ontological perspective, the above arguments imply a Parmenidean worldview for this study. According to Parmenidean reasoning, this study is also a good opportunity to learn about C&D waste minimisation. And knowledge about this topic can be progressively accumulated via contributions of subsequent studies (Paparone, 2010).

4.4.2. Epistemology

Epistemology is the study of 'knowing'. It refers to the question of how we know the world (Babbie, 2007; Feast & Melles, 2010). Epistemological enquiries revolve around evidence and reasoning to justify or clarify of one's understanding or belief (Fumerton, 2006; Poli, 2010). There are 2 competing epistemological strands: Positivism and Interpretivism.

Positivism seeks knowledge through the accumulation of verified facts without the human elements (Collis & Hussey, 2009). In positivism, reality exists outside of the researchers' perceptions (Weber, 2004). Therefore, the researchers are passive spectator of the event under investigation.

On the other hand, Interpretivism maintains that social phenomena do not exist independently of the researcher's own interpretations; instead it is the interpretation of social phenomena that affects social reality (Christou et al, 2010).

However, in both epistemological strands, a researcher's knowledge and perception is highly dependent on their historical, social and cultural background. This means the researchers must be careful with, and aware of the limitations of, their findings (Shakantu, 2004).

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The differences of these 2 epistemological strands are summarised in Table 5.

Table 5: Positivism vs. Interpretivism

Type	Positivism	Interpretivism
Aim and Focus	'measuring' phenomena	'explore' phenomena
Definition of Knowledge	accumulation and generalisation of verified facts	subjective interpretations of phenomena
View on Reality	reality is external to, and independent of, the researcher's perceptions, beliefs and biases	reality is a consequence of the individuals' interpretations
Researcher's Interaction	passive, as researcher is a neutral spectator of the event under investigation	active, as researcher must be involved in their investigations to understand the world from their subjects' viewpoint
Weakness	not successful in studying human behaviour due to the contrasting nature of assumptions used (orderly and regular) and actual interactions between players (complex and intangible)	the researcher could introduce their own beliefs and experiences to the research process, causing unnecessary interference and biases

Source: Inter alia, Chia (2002); Easterby-Smith et al (2002); Huglin (2003); Gray (2004); Cohen et al (2007); Kaboub (2008); Collis & Hussey (2009); Christou et al (2010); Nouman (2011)

It has been observed that both Positivism and Interpretivism have had significant influence on Western thinking, including management research (Davison, 1998). The differences between Positivism and Interpretivism in acquiring knowledge can be summarised in Table 6.

Table 6: Positivism vs. Interpretivism Summary

Type	Positivism	Interpretivism
Ontology	Person (researcher) and reality are separate.	Person (researcher) and reality are inseparable (life-world).
Epistemology	Objective reality exists beyond the human mind.	Knowledge of the world is intentionally constituted through a person's lived experience.
Research Object	Research object has inherent qualities that exist independently of the researcher.	Research object is interpreted in light of meaning structure of person's (researcher's) lived experience.
Method	Statistics, content analysis.	Hermeneutics, phenomenology, etc.
Theory of Truth	Correspondence theory of truth: one-to-one mapping between research statements and reality.	Truth as intentional fulfilment: interpretations of research object match lived experience of object.
Validity	Certainty: data truly measures reality.	Defensible knowledge claims.
Reliability	Replicability: research results can be reproduced.	Interpretive awareness: researchers recognize and address implications of their subjectivity.

Source: Weber, 2004

However, it has been argued that the seemingly substantial differences between Positivist and Interpretivist paradigms are in fact insignificant. And such differences are due to the choice of research method rather than any substantive meta-theoretical differences (Weber, 2004).

Further, it has been observed that no single research methodology is intrinsically better than others (Davison, 1998). Rather, a combination of methodologies can significantly improve the quality of research (Easterby-Smith et al, 2002). This is because Positivist and Interpretivist paradigms have their respective advantages and limitations. By using a combination of positivistic - interpretivistic approach, the researcher can exploit the

strengths of each paradigm while at the same time reducing their respective weaknesses.

4.5. Research Methodological Position

It has been argued that the nature of a research problem affects the ways the research solutions are produced (Tookey, 1998; Shakantu, 2004; Egbelakin & Wilkinson, 2008). As a result, a methodology should be chosen to reflect the specific needs of the research.

The nature of the problem in this research is to evaluate the economics of C&D waste minimisation strategies. However, Chapter 2 has revealed that there is a lack of understanding of factors affecting C&D waste minimisation strategies in New Zealand. This means there is an immediate need to identify these factors and explain the causal relationships between them. Only once this understanding is achieved that the research can evaluate the economics of C&D waste minimisation strategies.

The above requirement means that a sequential research approach is needed in this study. In this approach, the qualitative component must be undertaken before the development its quantitative counterpart. In other words, findings of the qualitative component are the basis for the design and development of the quantitative component.

Furthermore, as this research is the first study in New Zealand to establish a framework to evaluate the economics of C&D waste minimisation, it faces a lack of necessary theoretical perspective and empirical data to aid its development. It is anticipated that by utilising a multi-paradigm approach, this research can overcome this challenge.

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Based on the research aim, from an ontologically perspective a Parmenidean worldview is required in this research - for the development of an objective economic evaluation framework.

Epistemologically, to establish and understand factors affecting C&D waste minimisation in New Zealand, there is a need to interact with necessary operatives involved in the construction industry to obtain their perspectives on this subject matter. Subsequently, the researcher is required to interpret the results of such interactions in order to develop an economic framework for the evaluation of C&D waste minimisation strategies. As a result of this requirement, an interpretivistic approach is needed in this study.

At the same time, the research's requirement to develop an economic evaluation framework means that the study is mathematical and analytical in nature. This implies the research also requires a positivistic approach.

The above arguments point to the fact that there is a requirement to employ both positivistic paradigm and interpretivistic paradigm in this study. The decision to choose a mixed-paradigm approach to address this study's problem was not due to the inability to evaluate between the merits and demerits of each paradigm. Rather, it was due to the need of this study. It was also a result of the researcher's understanding that all research approaches are valuable if used appropriately and that a research can have elements of both positivism and interpretivism.

A mixed-paradigm approach will enhance the quality of the research's methodological enquiries. It is also anticipated the combination of positivistic - interpretivistic approach will ensure the economic evaluation framework developed in this research is applicable

to the New Zealand context. The research approach of this study is further elaborated in the subsequent sections.

4.6. Research Method

Because of the decision to employ a mixed methodology (as argued in Section 4.5), the research methods used in this research must be a combination of those belonging to the positivistic paradigm and those belonging to the interpretivistic paradigm.

Generally, a research containing a combination of research techniques is more advantageous than one relying on a single-method research approach. This is because in the multi-method approach, the strengths of individual research techniques can offset the weaknesses of others. At the same time, in the multi-method approach, individual research methods can complement each other, thus reinforcing the strengths of individual research methods.

The problem being investigated in this research is specific: to develop an economic framework to evaluate the economics of C&D waste minimisation strategies in New Zealand. However, as previously mentioned, there is a severe lack of necessary empirical information on, and around, C&D waste and C&D waste minimisation in New Zealand. Thus, a multi-method approach is utilised to overcome this challenge.

In this multi-method approach, there are two specific requirements. The first requirement is to establish baseline empirical data for the research problem. The second requirement is to develop an economic evaluation framework based on the empirical information obtained in the first requirement.

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In the first requirement, there is a need to identify and understand factors that may have significant effects on C&D waste minimisation strategies in New Zealand. This can be achieved by employing qualitative research techniques to obtain opinions from practising operatives in the New Zealand construction industry. The information provided by these individuals can be used as the basis for the development of the economic evaluation framework. Qualitative techniques to be employed in this study are semi-structured interviewing and elite interviewing.

In the second requirement, quantitative techniques are needed for the development of the economic evaluation framework. This need arises from the fact that the study is mathematical and analytical in nature; and only quantitative methods are capable of fulfilling this requirement. Quantitative method employed in this study is economic modelling and case study.

4.6.1. Interview Research

Interview is a familiar research method that has been used in many fields (DiCicco-Bloom & Crabtree, 2006). There is a wide range of interviewing approaches available, including: face-to-face interviews, telephone interviews, computer interviews, serial interviews or group interviews (Opdenakker, 2006). Further, each interview approach can have certain characteristics such as in-depth, structured, semi-structured, open-ended or closed. But the overall theme of interview research is to describe and understand the research topic through views of the interviewees (Valenzuela & Shrivastava, 2003).

4.6.1.1. *Semi-Structured Interviewing*

In this research, an interview research method is used to identify and understand factors as well as the aspirations of the New Zealand construction industry around C&D waste minimisation. The interviews will be carried out with practising construction professionals in New Zealand to obtain their opinions and feedback on this subject matter. The chosen interview method in this research shall be one-on-one semi-structured interviewing.

Semi-structured interview was chosen because of its 2 key strengths. First, semi-structured interviews allow interviewees to express their opinions on current C&D waste management practices in New Zealand, as well as the industry's zero C&D waste aspirations. Such information should contribute to the richness of data collected significantly. Second, there is a high degree of interactions between the interviewer (the researcher) and the interviewees. As a result, any complex issues or questions around this subject matter can be discussed and clarified instantly. Further, interviews with willing participants will be administered both before and after the economic modelling process. This is to ensure relevant variables can be identified for the modelling process and the modelling results can be administered properly in accordance to the research's requirements.

4.6.1.2. *Elite Interviewing*

This is a subclass of interview research. The term 'elite' originates from political science (Richards, 1996; Berry, 2007; Tansey, 2007). It refers to members in society who hold significant power and can decide in, or influence, policy-making process (Bozoki, 2011). However, recently it has acquired a broader meaning to include people of high levels of

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status, or hold significant responsibilities, within their professions or industries (Harvey, 2011).

Therefore, 'elite interviewing' is a research method undertaken by the researcher with people of high level of standing within their organisations, professions or industries in order to obtain their individual insights or first-hand account of a topic or a subject matter (Hochschild, 2009; Bozoki, 2011). It has been observed that elite interviewing contains a rich source data and other information for empirical research due to the wealth of knowledge and experience possessed by the interviewees (Tansey, 2007).

In this research, elite interviews are employed to obtain opinions and feedback from construction professionals in the New Zealand construction industry regarding the state-of-affairs of C&D waste minimisation and zero waste in this industry. For practical purposes, a working definition of 'elite' in this study is adopted from that in Hochschild's (2009) and Harvey's (2011). In particular, the 'elites' in this research are defined as 'someone who holds a senior management position within their organisation and who has at least 10 years of experience in the construction industry'.

Semi-structured interview and elite interview research methods are used together in this study to obtain opinions of construction personnel to explain how C&D waste minimisation fits in with the industry's overall sustainability aspirations. Interviews are employed in two phases: Phase 1 - before economic modelling and Phase 2 - after economic modelling. In the first phase, interviews are employed to obtain opinions of the chosen construction professionals. Interview results in the first phase will help this research establish the basis for economic modelling. In the second phase, interviews

with from the same professionals are used to obtain their feedback on the research results. Interview results in the second phase will help validate the study's outcome.

4.6.2. Modelling Research

Modelling is a positivistic method that has been widely used in economics (Caldwell, 1980). By definition, a model is artificial in nature - it is a product from model builder's conscious effort. In other words, it is an abstract representation of a phenomenon from the developer's point-of-view (Boland, 2000). In this sense, a model is neither 'realistic' nor 'ordinary'.

In economics, models are often based on mathematical concepts to represent or explain observed phenomena (Ayarkwa et al, 2011; DEFRA, 2011; US DOI, 2011; White, 2012; Gurtler-Schrieverhoff et al, 2014). Because of this abstracted representation, economic modelling has many built-in flaws (Drummond, 2005). These flaws include inadequate and/or excessive use of assumptions and data; problems in aggregating results; and selective reporting of findings.

In this research, economic modelling is employed for the development of an economic framework to evaluate C&D waste minimisation strategies. This choice aligns well with previous economic studies in waste management and waste minimisation (Goldman & Ogishi, 2001; Al-Hajj & Hamani, 2011; Ayarkwa et al, 2011; Kuslyaykina; 2013; Borisov, 2014) or zero waste (Doppelt & Dowling-Wu, 1999; Shen et al, 2004; Begum et al, 2006; Yuan et al., 2011; Hogg et al, 2011; Till, 2013).

However, upon understanding afore-mentioned issues associated with modelling research, efforts have been made in this research to minimise such modelling

drawbacks. This was done by collating qualitative data and quantitative data to ensure the economic models developed in this research are applicable to the New Zealand cases.

4.6.3. Case Study Research

Case study research is a well-understood, well-developed research method which has been extensively used in many areas (Yin, 2004; Baxter & Jack, 2008). Case study is a robust research approach as it allows for in-depth exploration and understanding of complex issues (Zainal, 2007). Various publications and studies on case study have been created (see, for example Yin, 2004; Yin, 2011 or Neale et al, 2006). But a definition offered by Davison (1998) summarises the essence of case study. In this definition, 'case study' is defined as a method to examine a phenomenon in its natural setting by employing multiple methods of data collection from one or a number of subjects, let them be people, groups or organisations. Further, in case study, the boundaries of the phenomenon being investigated are not clearly evident at the outset of the research and the research process often involves no experimental control or manipulation (Davison, 1998).

Case study research is employed to test the applicability of the economic evaluation framework developed in this study. Specifically, the economic evaluation framework will be applied to two case studies to investigate its generalisability and flexibility. Due to the lack of reliable data related to C&D waste, case study research is particularly useful for this research. This is because case study research allows the economic framework developed in this study to be applied to cases with readily-available data on C&D waste and C&D waste minimisation.

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Case study often involves 3 phases: exploring the research subject, evaluating the subject matter and testing research hypothesis (Barkley, 2006). Therefore, there are a number of factors to consider when deciding if case study approach is appropriate for the investigation at hand. These factors include the settings of the research (natural vs. controlled or contemporary vs. historical) and the theoretical background of the research (theory building vs. theory testing). It has been argued that case study is an advantageous methodology in situations where the first criterion of each factor prevails, such as research in contemporary setting that seeks to explore or establish a theoretical foundation for a study area) (Baxter & Jack, 2008; Yin, 2011).

In case study research, careful considerations must be given to research design, especially in the choice between single and multiple case studies (Baxter & Jack, 2008). Often the choice between these 2 research designs depends on many factors relating to the research such as its functional requirements or availability of relevant cases (Barkley, 2006). Single case study is used to examine a unique or representative case where the researcher is required to pay close and careful attention (Zainal, 2007). On the other hand, multiple case study research design is employed in situations where the researcher wishes to strengthen research findings via replication, cross-comparison or hypothesis testing (multiple case study research design is employed in situations where the researcher wishes to strengthen research findings via replication, cross-comparison or hypothesis testing (Yin, 2004). It has been argued that multiple case studies are more advantageous than single case studies due to its ability to convey richer information (Barkley, 2006; Yin, 2011).

As outlined above, this study employs two case studies to test the applicability and flexibility of the developed economic framework. As both case studies have rich

datasets, the economic evaluation framework can be applied directly to them without significant additional modelling work. Further, as the case studies are different in nature, by demonstrating the applicability of this framework to both cases, the research shows the framework developed here is indeed flexible and could be used in different situations.

4.7. Conclusion

This chapter has offered detailed discussions on the research methodology and research methods appropriate for this study. This was achieved through a systematic approach: from highlighting the philosophical position of the research; to justifying the underlying research design for the study; and, finally, to indicating the research techniques to be employed for subsequent research phases.

The next chapter will provide a basis for the development of the economic evaluation framework in this research.

**CHAPTER 5 - CONTEXTUALISING THE ECONOMIC
EVALUATION FRAMEWORK**

CHAPTER 5 – CONTEXTUALISING THE ECONOMIC MODEL

This research will address two knowledge gaps.

First, current C&D waste minimisation strategies in New Zealand do not seem to be effective. This is due to a lack of understanding of key drivers influencing those strategies. The current emphasis of C&D waste minimisation rests on moderations of people's behaviours through technology and guidelines such as the REBRI and Green Star/Green Building systems. Perhaps this approach was perceived as an easy way to reduce C&D waste. As a result, significant investments in terms of both monetary and effort have been spent on developing such systems. However, the fact that C&D waste minimisation in New Zealand construction has not improved significantly means that there is an urgent need for a new approach to address and minimise C&D waste.

As previously mentioned, construction's fragmentation has both risks and benefits for a strategy. As such, without proper considerations of these factors, a waste minimisation strategy is unlikely to succeed. One-dimensional considerations focusing on behaviours may appear to be too simplistic. Perhaps a better approach would be to look for systematic ways to minimise waste. This could be done by influencing key C&D waste minimisation drivers.

It has been shown in Chapter 2 that financial considerations are a key driver in construction. This means for a waste minimisation to succeed, it needs to demonstrate its economic benefits to construction stakeholders. By influencing the economic aspects of C&D waste minimisation, it is likely that construction will develop imperatives to minimise its C&D waste output. This is the fundamental rationale this research.

The second gap that this research will address is associated with the lack of techniques to evaluate the economics of a C&D waste minimisation strategy in New Zealand

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construction. While some efforts have been made to quantify the cost and benefit of C&D waste minimisation, they are mostly applicable to overseas cases (see, for example Begum et al, 2006; Tam & Tam, 2008; Yuan et al, 2011 or Yu et al, 2013). Currently there is no study in New Zealand exploring this area. This is a missed opportunity and one which needs to be addressed urgently so a good understanding of C&D waste economics can be achieved.

In this thesis, an economic evaluation framework is developed. It is intended that the framework is flexible enough to be used in various situations and for different waste streams. Efforts have been made to ensure this framework is appropriate for, and applicable to, the New Zealand construction industry. The economic framework is developed using a 2-phase approach.

In Phase 1, the research aims to establish the context of economic model via a series of interviews with elite practicing professionals in the New Zealand construction industry. These professionals will have at least 11 years of work experience in the New Zealand construction industry. Further, they must hold at least a senior managerial role within their respective organisations. The two restrictions above are used in this research to help limit the scope of this research to a small pool of very experienced individuals with in-depth understanding of the New Zealand construction. Further, these restrictions can ensure the feedback from these experienced practicing professionals is of high quality.

Once the baseline economic framework has been established and preliminary modelling has been undertaken, Phase 2 of the qualitative research will commence. In Phase 2, the research focusing on validation and confirmation of the assumptions and

claims made in the economic models. The preliminary results will be presented to the same group of interviewees to obtain their second-round feedback. It is anticipated that the feedback obtained in this round will be helpful for the researcher in the refinement of the economic framework.

5.1. Phase 1: Establishing context of economic model

In this phase, interviews with elite practicing professionals in the New Zealand construction industry were undertaken. To ensure the study meets all stringent requirements needed for an academic research, ethics approvals was sought and approved by the AUT Ethics Committee.

Elite interviews were carried out with seven highly experienced professionals using a semi-structured interview approach. These professionals come from different background, including:

- A Director of a project management company with 40 years of work experience in NZ
- A waste management consultant with 35 years of work experience in NZ
- A senior architect with 20 years of work experience in both the UK and NZ
- A senior project manager with 20 years of work experience in NZ
- A construction manager of a major construction company with 20 years of work experience in both the UK and NZ
- A construction manager of a major construction company with 15 years of work experience in both the UK and NZ

- A product category manager of a building merchant with 11 years of work experience in NZ construction supply chain management

As argued in Section 4.6.1.2, a significant valuable information can be obtained from the use of elite interviews due to the participants' wealth of knowledge and experience in construction. But at the same time, results obtained from the interviews may not be the reflection of views and opinions of the entire construction industry and are only applicable to this research due to a limited number of interviews undertaken. This could be a potential weakness of this research.

Interview questions and transcripts of the interviews with these professionals can be found in Appendix A and Appendix B, respectively.

5.1.1. States of affairs of C&D waste minimisation in New Zealand

The wealth of knowledge and experience possessed by these elite individuals has been particularly useful for this research. It has been revealed through the interviews that although it is possible to reduce and recycle C&D waste in NZ, waste reduction and waste recycling are not considered a high priority in practice. This is mainly due to two main reasons.

First, there is a perception in the industry that a waste minimisation strategy costs a significant amount of money to implement. Due to this perception, waste minimisation is not considered a high agenda by construction stakeholders. The result of this perception is that the uptake of waste minimisation in the New Zealand construction industry has been slow. Therefore, in order to improve waste minimisation in the New Zealand construction industry, there is an urgent need for a meaningful strategy to

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encourage the uptake of waste minimisation practices. Further, for such a waste minimisation strategy to be sustainable, there is a need for a good understanding of its economics so careful and proper planning can be undertaken to ensure its longevity.

Second, there exists a high degree of resistance for implementation of new ideas and concepts from the industry. Perhaps this is because of the traditional conservative nature of the construction industry. It was also found in the interviews that there is a lack of economic incentives offered to companies to minimise C&D waste. It has been argued that a robust incentive scheme can help increase the uptake of C&D waste minimisation significantly (Tam & Tam, 2008). This is because money is an important economic driver in construction and by having such a scheme could potentially increase the success rates of a waste minimisation programme. On the other hand, without enough economic imperatives, it is unlikely that the New Zealand construction industry will make changes to accommodate the adoption of new concept such as zero waste.

Although it is possible to model the economic impacts of a penalty – incentive scheme on a waste minimisation strategy, this option will not be explored in this study. This is due to practical reasons. Tam & Tam's (2008) model was developed specifically for, and tested solely in, Hong Kong. As a result of its restricted application, it is difficult to measure the robustness of this model as well as applicability to different locales. Moreover, the incentive model proposed by Tam & Tam (2008) would require a significant amount of work to modify to suit the New Zealand. This means by adopting Tam & Tam's (2008) incentive model into the current research would mean the scope of this research would be expanded significantly. This is an opportunity for subsequent studies to explore.

This research aims to address the first issue by developing an economic framework to evaluate C&D waste minimisation strategies in New Zealand.

5.1.2. Factors affecting C&D waste minimisation

It has also been reported from the interviews that a major variable that has significant effects on the success of a C&D waste management strategy in New Zealand is landfill charges. However, currently in New Zealand, C&D waste is not well categorised, leading to inconsistency in charging for C&D waste disposal. C&D waste charges are broadly treated the same as those for household waste and receives the same charges as the household waste. In other words, there is no disposal charging schemes specific for C&D waste. This has been considered by many interviewees as a weakness in the current regulatory framework related to waste minimisation in New Zealand.

As a radical way to tackle C&D waste, the interviewees have proposed that a high fee for C&D waste disposal is needed to force the construction industry to consider its responsibly. The consensus from the interviewees is that a landfill fee of \$150 per tonne is appropriate.

In term of costs, a specialist with many years of experience in C&D waste management has provided some cost information related to C&D waste. Specifically, the cartage rate of general C&D waste is estimated to be around \$2.50 per kilometre travelled. Further, tipping fees for the various C&D waste can be estimated as follows:

Table 7: Tipping Fees for C&D Waste in Auckland

Category	Location	Fees (\$ per tonne)
Rubbish	Hampton	\$65
Rubbish	Redvale	\$65
Rubbish	Huntly	\$40
Rubbish	Transfer Station Auckland	\$110

Hardfill products	Ward Demolition A	\$10
Hardfill products	Ward Demolition B	\$18
Hardfill products	Bombay Hills	\$10
Hardfill products	Three Kings	\$15
Timber recycling	Kalista	\$55
Plasterboard recycling	Tuakau	\$10

This information is useful and has been incorporated into the modelling process as a result.

5.1.3. Benefits of C&D waste minimisation

The interviews show that there are benefits of minimising C&D waste. These benefits come in forms of cost savings. The cost savings will be discussed in detail in Chapter 6.

At the same time, to eliminate C&D waste – i.e. zero waste – more money must be spent to improve the waste minimisation and recycling processes. In doing so, it is anticipated that the energy costs will increase significantly. However, waste disposal costs can be significantly reduced, as no waste goes to landfill. As such, the formulae of benefit calculations developed in Chapter 6 must satisfy this requirement.

Overall, all information provided by the interviewees is useful for this study the in development of the economic evaluation framework for the research.

5.2. Stakeholders in Waste Minimisation

It was found in the interviews that a C&D waste minimisation strategy, if implemented, will affect, and be affected, by many stakeholders within the New Zealand construction industry. It is hence important to understand the stakeholders that are, and/or may be, involved in, or affected by, the strategy.

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Key stakeholders identified through interviews include: client (building owner), project manager (client side), designers, prime contractors and specialist waste management contractors.

In this research, a 'client' is defined in this research as the 'building owners'. Under this definition, the 'client' can be assumed to have full ownership of their buildings and can make decisions to change and alter the buildings. It can be further assumed that when the client is a rational being and only makes investment decisions under sound economic analyses. Decisions made by the client's regarding the changes of their buildings include, but not limited to, renovation, remodelling, demolition and reconstruction of the building. It can be also assumed that such changes can take place at any point in time that the client sees fit. However, the client must be responsible for all costs associated with his or her decisions regarding such changes.

A project manager (client side) is defined in this research as someone working for the client to manage the entire project on their behalf. The project manager can either be an internal party from within the client's organisation or they can be an external party hired by the client for the duration of the project under consideration. Based on information gathered from the interviews with project managers, the project manager (client side) is typically responsible for all aspects of the project delivery, including, but not limited to, client briefing, financial and cost administration, project programming, consultant engagement, design management and project delivery supervision. Due to their deep involvement in the entire project, the project manager often has a good understanding of the project. They can identify areas that need to be improved as well as opportunities to reduce waste.

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'Designers' is a broad term defining people or groups of people who are involved in the design management and/or design of the project. In this research, designers may include, but not limited to, project managers, design managers, planners, land surveyors, architects and engineers. Sometimes, depending on the projects, the contractors and specialists sub-contractors may be involved in aspects of the design process. The interviews with architects, contractors and waste management contractors showed that in waste minimisation-focused project, it is beneficial to get contractors and specialist waste management contractors involved early in the design process so areas and opportunities to reduce waste can be identified early and understood by all parties.

The prime contractor in a building project is defined in this research as the lead company responsible for the construction and delivery of the project. Interviews with contractors revealed that main contractors in New Zealand often operate as Construction Managers. This means that they often focus on project supervision, with work packages sub-contracted to their sub-contractors. The interviewees confirmed that this practice allows the main contractors to minimise their project and organisational risks (by means of distributing them to the sub-contractors). In waste minimisation, often main contractors would require their sub-contractors to take actions to reduce and minimise waste, thus passing all waste minimisation responsibilities to the sub-contractors. Therefore, from the main contractor's perspective, they are not directly affected by a waste minimisation strategy in a project. On the other hand, by taking part in such a strategy, they could gain significant benefits such as, but not limited to, possible earnings from design consulting, free training in waste minimisation for key staff and significant marketing and public relations exposure from being involved in such a waste minimisation-focused project.

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Specialist waste management contractors often involves in the waste management process of the project's physical wastages. As the role of this group of contractors is specific and specialised, they can add significant values to a waste minimisation-focused project. It was revealed in interviews with main contractors and specialist waste management sub-contractors that in a waste minimisation-focused project, if the contractors are involved early in the project, including at the design stage, it is likely that they will take proactive approaches to reduce and minimise wastages during construction process.

The interviews have also revealed a *laissez-fair* attitude in the New Zealand construction industry regarding C&D waste management. Often once contract is signed, and construction cost for contractor is fixed, the opportunity to minimise waste often rests with the subcontractors carrying out the work onsite. The contractor then focuses their effort on making sure the subcontractors meet project timelines and objectives in order to earn money. At the same time, the subcontractor must make sure they adhere to all waste minimisation requirements imposed by the main contractor, and meet project deadlines. This means opportunities to add values to waste minimisation and zero waste at contraction stage is limited. The construction management interviewees indicated that significant values could be gained in relation to waste minimisation at the design stage.

Based on this feedback, the focus of this research is therefore rests on the design-out-waste component as it helps narrow down the scope of the current research.

5.3. Research Focus

5.3.1. Stakeholder Groups

In this research, the economic framework will focus on the economics of C&D waste minimisation and zero waste from the client's perspective. The reason to focus on this stakeholder group is two-fold. First, the clients are responsible for paying for all materials and services relating to the construction and/or demolition of their building. As such, they can have significant influences on waste minimisation practices in the construction and demolition processes. Based on the assumption that the clients are rational people who make investment decisions based on sound economic analyses, it is reasonable to assume that the clients wish to minimise the amount of waste generated in their projects if and only if the cost associated with waste minimisation does not outweigh the benefits that can be obtained from such activities.

Second, there are many groups involved in C&D waste minimisation. Aside from the clients, groups having vested interests in waste minimisation in a building project include, but not limited to, project managers, consultants, architects, engineers, contractors and specialist waste management contractors. As shown in Chapter 2, each of these interest groups has their own economic agendas and objectives for undertaking waste minimisation and zero waste. To understand the economic agendas and objectives of these interest groups in relation to C&D waste minimisation and zero waste would therefore require significant amount of in-depth studies. In relation to this research, it would mean the scope of this research would be significantly expanded beyond its time limit of three years of study. To ensure the scope of the study remains manageable, this study only focus on the client group. The zero-waste economics and

considerations from the viewpoints of other interest groups can be studied in detail by subsequent researchers.

5.3.2. Focus on processes

The qualitative results show that there is a consensus among interviewees that a C&D waste minimisation strategy has the greatest impacts at the design stage. This is because implementing waste minimisation strategies at the design stage such as design-out-waste does not generally increase the design cost significantly. In fact, it has been confirmed that sometimes the costs for design-out-waste designs are the same as the costs for non-waste minimisation-focused designs. However, due to a perception that the former design types are more expensive than conventional designs, waste minimisation-focused designs are often ignored by stakeholders.

In addition, it is the design stage that the client has significant influence and inputs in their projects. Often once the contract is awarded, the responsibility of waste minimisation rests with the contractors. The client has a minimal influence on waste minimisation at the construction stage. Therefore, from the client's perspective, they need to focus on the stage that they can maximise their influence on the matter of waste minimisation; and that is the design stage. At the design stage, the client can work with the design team as well as contractors to ensure their ideas and principles are met. Also, it is at this stage that the client can set agendas on, and around, waste minimisation. By working alongside contractors, not only can the client put their ideas and requirements across to the contractors but the client also has an opportunity to assess the capability of the contractors and whether they are suitable for the project.

Considering the information above, this research will only consider the design stage for modelling purposes. The study will also explore the design-out-waste aspect within the design stage to understand the costs and benefits this process can offer to the client. The sole consideration of design stage in this study is for practical purposes. By focusing on this area, this research can limit its scope to a manageable level. This means this research will not take into consideration of waste minimisation during construction stage and any stages thereafter. Instead, further researches can be undertaken by subsequent studies to investigate the economics of zero waste in these stages.

Chapter 6 will discuss assumptions and modelling procedures in detail.

5.4. Phase 2: Validation

Phase two of the qualitative research was undertaken upon the completion of the economic evaluation of the case studies.

Telephone interviews were made with the same professionals who participated in the phase one interviews.

Findings of Phase 2 are summarised in Chapter 8. Phase 2's transcript is included in Appendix D.

5.5. Conclusion

This chapter has provided a basis for a development of the economic evaluation framework in this study. This was achieved using a two-phase approach. In the first phase, a theoretical perspective for this research was provided using the semi-

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structured elite interviewing method with a group of high profile and highly experienced practising construction professionals. The interview results were used to develop an economic evaluation framework that was appropriate for, and applicable to, the New Zealand construction industry.

The second phase was undertaken upon the completion of the economic modelling of the case studies. Findings in this phase helped confirm the research findings. Further, they provided information needed for future work.

Chapter 6 discusses how this framework can be used to evaluate the economics of minimising a number of waste streams in a new construction project. While Chapter 7 describes how it can be applied to the evaluation of the minimisation of brick waste in a refurbishment project.

**CHAPTER 6 - DEVELOPMENT OF THE ECONOMIC
FRAMEWORK**

Once relevant information regarding the state-of-affairs of C&D waste management and waste minimisation in the New Zealand construction industry has been obtained from interviews, the next step is to develop an economic framework to evaluate values of waste minimisation and zero waste.

6.1. Overview of the Economic Framework

The economic evaluation framework developed in this study is mathematical based. However, the information obtained from the interviews has also been used as the basis and incorporated into the framework development process to ensure the framework remains relevant to the New Zealand case.

In mathematical modelling, a model is a product of its builder's conscious effort. In other words, it is an abstract representation of a phenomenon from the developer's point-of-view (Boland, 2000). Researchers hence have freedom in choosing their study subjects and study objects.

6.2. Focus of this Research

As argued in Chapter 5, the economic evaluation framework in this research will focus on the assessing the economics of C&D waste minimisation and zero waste strategies from the client's perspective.

Further, also shown in Chapter 5, to limit the scope of the research this research is limited to the design phase only, with an exploration of the 'design-out-waste' component to understand its economic values to the client. By limiting the scope to the

design stage, this research will not take into consideration of waste minimisation during construction stage and any stages thereafter. Instead, further researches can be undertaken by subsequent studies to investigate the economics of zero waste in these stages.

6.3. Economic Framework: The Concept

As mentioned in the literature review, currently there is a lack of a theoretical basis for the 'zero waste' concept, despite its successful applications worldwide. In turns, the lack of an overall theoretical framework for zero waste seems to have discouraged researches in this area, as evidenced by the limited literature in body of knowledge in this area. The lack of an overarching theoretical framework for zero waste also means that each researcher working in this area must develop their own conceptual model to represent zero waste within their study.

Due to a lack of a pre-existing theoretical framework for zero waste in construction, there is an immediate need in this study to formulate a conceptual framework to undertake the economic evaluation of zero waste in construction. Further, due to the lack of preceding theoretical models in zero waste, the theoretical economic framework developed in this research will be based on those for related concepts such as construction waste management and construction waste minimisation.

Many waste management and construction minimisation frameworks for construction have been used as references. They include the work of Tam & Tam (2008), Jain (2012), Dajadian & Koch (2014) and Fadiya et al (2014).

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Overall, these waste management and waste minimisation models have provided useful references for this research. They have enabled the researcher to understand and refine the waste management and waste minimisation processes to develop a theoretical framework for zero waste in New Zealand building construction.

The economic hierarchy of C&D waste management and C&D waste minimisation in the New Zealand building sector is presented graphically in Figure 4. The map was produced using flow diagrams. In this diagram, each process is represented by a node and the relationships between the nodes are represented by edges connecting them. As each process may be affected by another, the diagram employs directed lines to show the effects of one process on another.

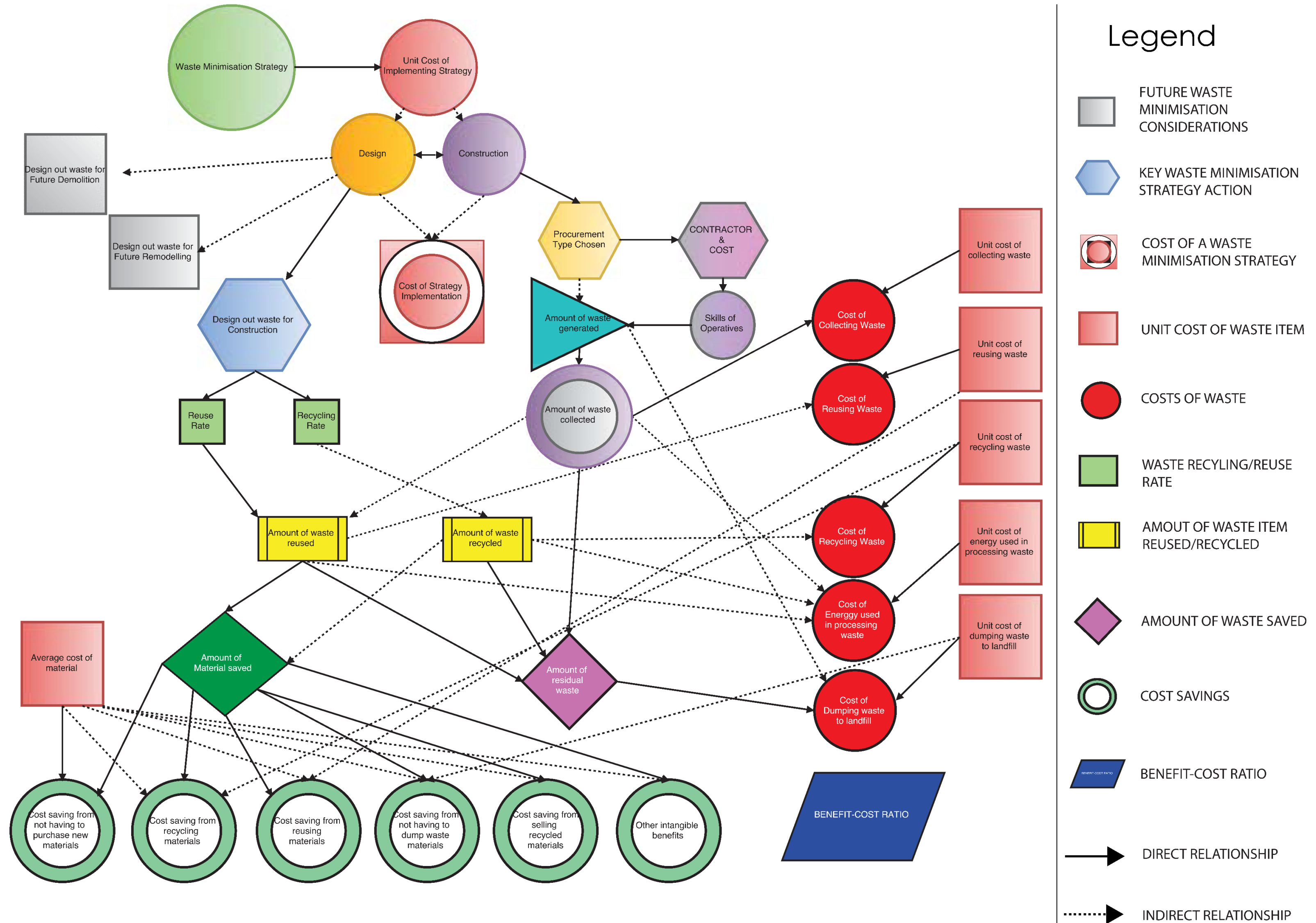
It is believed that by using flow diagram, it is possible to demonstrate the complex relationships between processes in building construction in trying to achieve zero waste. Further, the visual representation of this theoretical zero waste framework allows subsequent researcher to review it and, potentially, enrich the framework by adding more relevant processes.

In the context of this research, the map of construction zero waste is unique, as it was developed based on interviews with, and feedbacks from, practising professionals in NZ construction. Further, as reported earlier, zero waste is a relatively new area of study and hence containing of a limited body of knowledge. In the context of construction in New Zealand, there have been no studies exploring this area to date that the researcher is aware of. As a result, this research contributes to the body of knowledge in zero waste, particularly in construction context.

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The uniqueness of this research even extends to the way which the data were collected and the flexibility offered by the framework offers. The economic evaluation framework developed in this study allows users to evaluate the economics of minimising individual wastes as well as a basket of waste types.

Figure 4: Theoretical Hierarchy of C&D Waste Minimisation in New Zealand Construction



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In this conceptual framework, two key components of any waste minimisation strategies are design-out-waste and construction considerations to achieve waste minimisation. These two key considerations in turns directly and/or indirectly affect several other components such as amount of waste generated or amount of waste salvaged.

Since each component in the waste minimisation strategy has their own associated unit cost(s) and/or benefit(s), one can follow the directions of arrows to calculate direct (or indirect) costs and benefits for all components.

Finally, a Benefit-Cost Ratio can be calculated by dividing the sum of all benefits by the sum of all costs.

6.4. Modelling Assumptions

For this research, several modelling assumptions have been made to ensure the economic evaluation framework functions within the research scope. These modelling assumptions are divided into three broad categories: Market Assumptions, Design-Out-Waste Assumptions and Assumptions on Waste Minimisation Strategies.

6.4.1. Market Assumptions

Market assumptions refer to a set of conditions needed to ensure the modelling process work smoothly. In the real world, there are often many interacting factors that affect the economy and economic activities. These factors may include, but not limited to, fluctuations in economic cycles, migrations of goods and people; and external events such as war and disasters. However, for this research, these extreme factors are ignored in order to simplify the economic modelling process. By assuming these factors

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have zero effects on the situation under consideration, i.e. zero waste, the research can focus on the essence and explain in detail the inner working of the economic evaluation framework.

Another key market assumption made by this research is that the market is fluid and remains in a perfect equilibrium. In other words, there is strong correlation between supply and demand within the existing market. This means in the current market setting whatever is sold on the market gets bought by willing buyers. Vice versa, whatever the customer wishes will be fulfilled by willing supplier of goods and services. This assumption is used to match sellers and buyers of goods and services in this research. By using this assumption, the research can remain within the stated scope of study, as there would be no requirements to model the buying-selling behaviours that may exist in the construction industry's market place.

Lastly, this research assumes the perfect economic efficiency exists within the market considered in this research. Specifically, it is assumed that in the New Zealand building construction industry, risks and associated benefits (AB) of assuming such risks get rewarded accordingly. The mechanism for transferring risks and ABs is through contracts and contractual agreements. Further, all parties will honour their promises and act accordingly to make sure such promises are honoured. By having this assumption, the research can ensure all parties, including designers, contractors and sub-contractors get paid for any risks that they assume for parttaking in a waste minimisation-zero waste strategy.

6.4.2. Design-out-Waste Assumptions

As discussed in Chapter 5, the focus of the economic evaluation modelling rests on design out waste. It is therefore important to understand key areas that the economic model can address as well as key assumptions related to areas that the economic model cannot address.

6.4.2.1. *Actors involved in design-out-waste processes*

It has been well documented from WRAP studies that to design out waste there must be commitments from everyone involved in the design process (WARP, 2009, 2011). From the interviews undertaken for this research, it was found that it is the design stage that can deliver the biggest values to a waste minimisation strategy, and for a relatively small cost. Further, it has been suggested from the interviews that there is a need for every major project partners to be involved in the design process to achieve the maximum design-out-waste outcomes. Specifically, it has been agreed by interviewees in this study that the key stakeholders involved in the design-out-waste process include: the Project Manager (client side), the Planner, the Surveyor, the Architect(s), Engineers (Traffic Engineers, Structural Engineers, Geotechnical Engineers, Mechanical Engineers and Services Engineers), the Main Contractor and the specialist Waste Management Contractor. Table 8 summarises the interviewees' consensus on responsibilities of each key design-out-waste actor.

Table 8: Responsibilities of Stakeholders in Building Construction

Actor	Responsibility
Project Manager (client side)	Make sure the designers and contractors deliver design and construction solutions that can achieve the desired waste minimisation goals
Planner	Ensure development meet all regulatory requirements, include those related to waste management
Surveyor	Ensure surveying work is accurate and all land information is properly articulated and clearly marked up on plans. This will reduce uncertainty for

	subsequent designers such as architects and engineers (geotechnical and structural engineers). In turns, the accurate information will help reduce process waste in the design process
Architect	Ensure the design meets all requirements, including waste minimisation requirements, set out in the client briefing document. Where appropriate, the architect chooses materials that can have maximum level of recyclability and/or reusability. The architect must think about the potential effects on waste generation in later stages in the life of the building (i.e. during remodelling/refurbishment and demolition of building)
Engineers	Responsibilities of engineers are similar to that of the architect in that they must think of the recyclability and reusability of materials in later stages of the building’s life. This thinking must permeate throughout the design process and through all engineering disciplines listed above to ensure the design can achieve the maximum levels of waste minimisation
Main Contractor	The contractor’s role in the design process is to ensure the constructability of the proposed design. In other words, they make sure that the design can be translated to actual work onsite. As such, they must be involved early in the design process in order to provide practical advices to the designers
Waste Management Contractor	Similarly, the specialist waste management contractor can provide useful information to the design team about the recyclability of materials and whether the stated waste minimisation goals are achievable. They have an important role in ensuring the waste generated onsite can be recycled and/or repurposed. As such they should be involved early in the design process in order provide advices on the recycling aspect of the project.

6.4.2.2. Considerations in design-out-waste processes

There are several considerations in the design-out-waste process. From the interviews, it was found that the key consideration is materials. It was revealed that in a waste minimisation-focused project, significant design hours are spent on researching suitable materials. For instance, in one project, the designer spent up to 500 design hours to research suitable materials to ensure wastage was minimised.

The interviewees in this research indicated that significant wastages in construction were mainly or partly due to the low or inadequate level of skills of tradesmen. Interviewees reported that the level of skills possessed by workers on construction sites has decreased significantly in the last 25 years - and this partly contributes to the significant waste generated from works onsite.

As such, the interviewees suggested up-skilling of construction operatives is needed urgently. However, this costs money and it needs to be considered carefully. For the purpose of this research, the consideration of training/up-skilling operatives, and its associated costs, is outside the scope of the study and will not be included in the calculation. Instead, subsequent studies are needed to investigate this area further.

Another area that could be considered in the design-out-waste process is the identifications of areas that waste can be reduced. This can be achieved by careful considerations by designers and in close consultation with contractors.

6.4.2.3. Behavioural Assumptions

In this research, there exists an implicit assumption that all parties in a project are committed to achieving the stated waste minimisation goal. This assumption is useful because the behaviours of individual party involved in the design-out-waste process lie outside of the scope of this research. And having this assumption built in the study helps eliminates the need to investigate this area in detail.

Specifically, the research assumes that all parties in the design-out-waste process will do everything that they can to achieve their stated waste minimisation objectives. Table 9 summarises behavioural assumptions for each design-out-waste stakeholder considered in this study.

Table 9: Commitments of Stakeholders

Actor	Commitment Assumption
Client	commit money and resources to ensure waste minimisation target is met
Project Manager (client side)	dedicate time and effort to ensure all parties meet stated waste minimisation goals
Designers (Architects & Engineer)	dedicate time and effort to ensure designs meet desired waste minimisation objectives where appropriate, designers will identify opportunities to minimise waste and maximise values for clients

Main Contractor	committed to waste minimisation at every construction stage make effort to ensure all subcontractors meet required waste minimisation goals where appropriate, contractor will identify opportunities and take actions to minimise C&D waste
Waste Management Contractor	committed to waste minimisation via recycling and repurposing materials where appropriate, waste management contractor shall maximise the recycling rates of materials

6.4.3. Assumptions on Waste Minimisation Strategies

6.4.3.1. Waste strategy assumptions

In this research, there are several assumptions on waste minimisation strategies are employed. These assumptions are made for economic evaluation modelling purposes based on the information provided by interviewees. Specifically, the research assumes there are seven (7) waste minimisation strategies (see Table 10). This assumption is based on interviewees’ feedback and classifications of waste minimisation strategies.

Table 10: List of C&D Waste Minimisation Strategies

Waste Strategy							
Strategy	1	2	3	4	5	6	7
Description	Waste to Landfill	Waste Reduction	Waste Reduction	Waste Reduction	Waste Reduction	Waste Reduction	Zero Waste
Reduction Rate	0%	5%-10%	11%-30%	31%-50%	51%-70%	71%-95%	100%

These strategies range from the simple form (landfilling waste) to complex form (zero waste). The reason for the range of strategies above is for modelling reason: it is intended that the research can demonstrate the economics of the various strategies under the same set of assumptions. The scenario analysis capability demonstrated by the framework is useful for cross comparison between waste minimisation strategies.

The framework can help explain the relative economic benefits, or otherwise, of zero waste in construction context.

6.4.3.2. Design cost assumptions

As waste minimisation strategies get more and more complex, it is assumed that the cost of design will increase proportional to the respective design complexity of each strategy. This increase also affects the design-out-waste component, as it is part of the design cost. In other words, strategies requiring more rigorous waste minimisation requirements would cost more for the same step than their less rigorous contemporaries. Table 11 below summarises the incremental rates of design fee from simple strategy (landfilling waste) to the most complex and ultimate strategy (zero waste). These rates are provided by architectural and engineering interviewees based on their experiences.

Table 11: Assumed Increases of Design Fees

From strategy to strategy	Rate of design fee increase
1 TO 2	20%
2 TO 3	10%
3 TO 4	10%
4 TO 5	10%
5 TO 6	15%
6 TO 7	30%

Also, interviews with client-side project managers and architects revealed that since the design cost is a small portion of the total project cost, such increases are unlikely to deter clients from zero-waste commitments. This is because given the significant benefits clients can get from marketing and promotion, such small increases in design costs are often considered insignificant by the clients.

6.4.3.3. Energy cost assumptions

There is another implicit assumption that underlies this research. It has been assumed that the increases in waste strategy costs come from the fact that more energy is required to process waste and turn them into usable products. This extra energy is required at every step along the recycling process, from handling and sorting waste onsite to transport waste to processing plants, to recycling waste and repurposing waste to usable products. For this research, it is assumed that the energy cost increases by 25% for Level 6 strategy compared to the Level 1 strategy and by 50% for Level 7 strategy compared to the Level 1 strategy. This assumption was made based on feedback from the specialist waste management contractor.

It is anticipated that the increments in energy requirements and consumptions at every level will in turns have significant implications on the costs associated with the waste minimisation strategies.

6.4.3.4. Benefit assumptions

It has been suggested by the interviews that there are financial benefits associated with minimising C&D waste. The interviewees in this research perceive that financial benefits come in forms of cost savings achieved by the client from minimising waste and sales of recycled/repurposed materials to third-parties.

As more waste is diverted from landfill, more cost savings can be realised by the client - and to a degree by the lead contractor also. These cost savings come in forms of transportation cost savings, purchasing cost savings and cost savings from disposing of less waste. As waste minimisation strategies get progressively more rigorous, the cost savings associated with such respective strategies and which can be realised by the client (and lead contractor) grow significantly.

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At the same time, as more waste is being diverted from landfill, the client can also gain more intangible benefits associated with it. Such intangible benefits include, but not limited to, improved reputation, improved morale within their current workforce and/or improved media coverage. It is often difficult to quantify these intangible benefits. However, they exist and can offer significant 'soft' values to the client as well as organisations involved in the project. Although intangible, these 'soft' values can be significant to all organisations. As a result, these 'soft' values should acquire a dollar value associated with them.

Although it is possible to model and calculate the dollar values of the intangible benefits, by doing so would mean the scope of this research would be significantly expanded. Besides, the intangible benefits remain to be a small component of the benefit modelling in this thesis. It is hence not justifiable to expand the scope of the study significantly to accommodate for a small component of the model. Therefore, for this study, it was decided by the researcher that the monetised values of the intangible benefits are assumed instead of being calculated. The amount of assumed intangible benefits varies from project to project. As a result, the corresponding monetised values of such intangible benefits will also vary from one project to the next. These monetised values of intangible benefits will be discussed in detail in the case studies in Chapter 7 and Chapter 8 respectively.

6.5. Economic Framework: The Models

The economic models for the framework are developed because of the theoretical economic framework presented above. These models are mathematical-based and

CHAPTER 6 – DEVELOPING THE ECONOMIC FRAMEWORK

have been developed from the ground up for this research regarding a model offered by Tam & Tam (2008). In other words, these models are mathematical representations of a theoretical framework for zero waste. As the theoretical framework developed in this thesis is unique to New Zealand, the economic models derived are also unique to the New Zealand case.

Despite several similarities between the framework in this research and that in Tam & Tam (2008), they are different in principle. Tam & Tam's (2008) study focused on mechanisms to motivate C&D waste minimisation – in this case an incentive scheme. Although Tam & Tam (2008) showed having an incentive scheme like a step-wide incentive can help reduce waste, it lacks the economic rationale as to why such a scheme should be implemented. On the other hand, this research focuses on understanding the economic rationale for undertaking waste minimisation strategies such as a zero-waste scheme in New Zealand. In this sense, the current research, with some modifications, can address the fundamental rationale underlying Tam & Tam's (2008) work. However, Tam & Tam's (2008) work has provided good insights into economic modelling in relation to C&D waste and as such it has been utilised as a useful reference source in the development of the economic models in this research.

Table 12: List of Modelling Variables

Variable	Description
Q_i^e	estimated quantity of material i
Q_i^a	actual quantity of material i
P_i^m	market price of material i (new)
P_i^r	resale price of reused/recycled material i
P_a^m	average market price of new materials
P_a^r	average resale price of reused/recycled materials
WR_i^e	expected wastage rate of material i
WR_i^a	actual wastage rate of material i (measured by waste management contractor)

RR_i	recycling/reusing rate of material <i>i</i>
A	intangible benefits
C_c	cost of waste collection
C_d	cost of waste dumping
C_m	material cost
C_{des}	cost of design
C_{proj}	project value
C_{rc}	cost of recycling waste
C_{ru}	cost of reusing waste
C_{en}	cost of energy used in recycling and reusing
C_{total}	total cost of waste
U_c	unit cost of waste collection
U_t	unit cost of waste transportation
U_{i^{rc}}	unit cost of recycling waste <i>i</i>
U_{iru}	unit cost of reusing waste <i>i</i>
U_{i^{en}}	unit cost of energy in processing and recycling waste <i>i</i>
T_{des}	amount of time spent on design-out-waste
P_{des}	average design fees/charges

6.5.1. Economic Models for Benefits of Zero Waste

In any project, quantities of resources are often estimated in advance by professionals such as quantity surveyors. For each material, the estimated quantity Q_i is known before any work is undertaken. However, as work onsite commences the amount Q_i^e may change accordingly to the specific requirements for each type of work onsite. The quantity of material *i* that is required by the work onsite is denoted as Q_i^a .

If the amount of estimated quantity Q_i^e is greater than the actual quantity amount required Q_i^a , then the amount of material that has been saved is

$$\Delta Q_i = Q_i^e - Q_i^a \quad (1)$$

There is an implicit assumption in Equation 1. It assumes that for planning the project, the client and their team do not order the entire amount Q_i^e . Rather, they only order what is needed at any point in time. Indeed, if they order the whole amount Q_i^e and later

find out what they require (Q_i^a) is less than estimated, then the value ΔQ_i represents wastage for material i . For this research, the above implicit assumption holds true.

As the client does not need to buy the amount ΔQ_i , the cost saving of materials for the client is:

$$B_p = \sum_{i=1}^m \Delta Q_i \times P_i^m \quad (2)$$

6.5.1.1. Cost saving on waste generation

It is anticipated that by implementing a C&D waste minimisation strategy, the amount of waste generated in a project minimised. At the planning stage, the client’s consultants such as architects and/or quantity surveyors can often estimate one, or a range of, wastage rate for each material. This estimated wastage rate is denoted by WR_i^e . Accordingly, the amount of waste for each material can be calculated using the formula:

$$W_i^e = Q_i^e \times WR_i^e \quad (3)$$

However, once construction commences, the rate WR_i^e can change, as the contractor and subcontractors can monitor and track the waste generated and produce the actual wastage rate WR_i^a for each material. As a result, the amount of W_i^e is changed to W_i^a by formula:

$$W_i^a = Q_i^e \times WR_i^a \quad (4)$$

Under the same assumption as Equation 2, the quantity of the waste that has been reduced as a result of the C&D waste minimisation strategy (ΔW_i) is given in the formula:

$$\Delta W_i = W_i^e - W_i^a \quad (5)$$

It has been further assumed that although the contractor is responsible for paying waste management contractor and other related parties such as landfill owners and councils for waste disposal. This money paid by the contractor was in fact charged to the client by the contractor. Therefore, the client is the ultimate payer for all costs associated with the waste minimisation strategy, including collection, treatment and disposal of C&D waste.

As less waste go to landfill, the client can save money from waste disposal to landfills.

The cost saved on waste disposal to landfill for each type of waste is:

$$S_i^l = \Delta W_i \times \text{landfill charge} \quad (6)$$

The total cost saving of waste disposal (on all materials) for the client is a sum of cost savings of waste disposals (on individual materials).

$$B_d = | \sum_{i=1}^m S_i^l | \quad (7)$$

6.5.1.2. Cost saving from reusing and recycling

As more emphasis is placed on reuse and recycling of materials, it is anticipated that the client can also make cost savings here as well. As materials can be recycled and reused, it is assumed that more materials can be saved. The amount of saved material i is:

$$SM_i = \Delta W_i \times RR_i \quad (8)$$

It is also assumed that due to the availability of recycled materials for the project, the project experiences there is less demand for new materials. This means instead of paying for a full price of the new materials, the clients can pay for a fraction of that price

for comparable recycled products. The difference between the price of new material i and that of the reused/recycled product i is:

$$\Delta P_i = P_i^m - P_i^r \quad (9)$$

In case the materials are amalgamated, the average price of all materials is used instead.

$$\Delta P_a = P_a^m - P_a^r \quad (10)$$

The main savings for the client in product i is the product of the price difference and the amount of saved material i :

$$CS_i = SM_i \times P_i \quad (11)$$

Finally the total cost savings of materials is:

$$B_m = \sum_{i=1}^m CS_i \quad (12)$$

6.5.1.3. Revenue from selling construction recycled materials

In addition to the above cost savings, the clients also have opportunities to on-sell their products to a secondary market. The on-sold products can be recycled and repurposed materials or excess new materials. This presents an additional benefit to the client and can be captured in the following formula:

$$B_r = \sum_{i=1}^m \Delta W_i \times (P_i^r - U_i^r) \quad (10)$$

6.5.1.4. Total cost saving

Finally, the total cost savings available to the client is a sum of individual cost savings discussed above plus intangible benefits to the client as a result of the waste minimisation strategy.

$$B_{cs} = B_p + B_d + B_m + B_r + A \quad (11)$$

6.5.2. Economic Models for Costs of Zero Waste

The cost models in this study are considered below. There are a number of assumptions used in the calculations of cost models. These assumptions are the results of interviews with practicing professionals in New Zealand construction.

1. The cost of design-out-waste C_{des} is a product of the time taken for the designer to design out waste and the price for such activities;
2. The cost of the waste policy of a project C_p is a percentage of project cost C_{proj} . As each construction project is different, it is not possible to assess what this percentage should be; but based on interviews with a number of experienced Project Managers and Architects, a rate of 0.1% – 0.5% can be assumed.
3. The amount of waste residue is the amount difference between the waste generated and the saved materials SM_i
4. The cost of waste collection C_c of individual waste is a product of the sum of all waste and the unit cost of waste collection
5. The cost of waste disposal C_d is a product of the amount of waste residue and the landfill charge.
6. The cost of waste recycling C_{rc} is the product of the reduced waste and the unit cost of recycling. The amount of reduced waste is a product of the amount of saved materials SM_i and the unit cost of recycling
7. The cost of waste reusing C_{ru} is the product of the reduced waste and the unit cost of reusing waste. The amount of reduced waste is a product of the amount of saved materials SM_i and the unit cost of reusing waste

8. The cost of energy C_{en} is a product of sum of all saved materials SM_i and the unit cost of energy
9. The cost of construction material waste C_m is a product of all residue waste and the average market price for all new materials
10. The total cost of waste C_w is the sum of all cost components above.

The cost formulae are summarised in table below.

Table 13: Key Cost Formulae

Cost Component	Formula	Number
Cost of design-out-waste	$C_{des} = T_{des} \times P_{des}$	12
Cost of waste policy	$C_p = 5\% \times C_{proj}$	13
Cost of waste collection	$C_c = (\sum_{i=1}^m \Delta W_i) \times U_{cw}$	14
Cost of waste dumping	$C_d = \{\sum_{i=1}^m \Delta W_i - SM_i\} \times \text{landfill charge}$	15
Cost of recycling waste	$C_{rc} = \sum_{i=1}^m SM_i \times U_{rc}$	16
Cost of reusing waste	$C_{ru} = \sum_{i=1}^m SM_i \times U_{ru}$	17
Cost of energy	$C_{en} = (\sum_{e=1}^E \Delta W_i) \times U_{en}$	18
Construction material waste cost	$C_m = \{\sum_{e=1}^E \Delta W_i - SM_i\} \times P_a^m$	19
Total Cost of Waste	$C_w = C_{des} + C_p + C_c + C_d + C_{rc} + C_{ru} + C_{en} + C_m$	20

6.5.3. Benefit-Cost Ratio

Finally, the Benefit-Cost Ratio is the ratio between the monetised benefits that the client obtains from managing and minimising C&D waste and the costs associated with such activities. It is represented in Equation 21 below.

$$BCA = \frac{B_{cs}}{C_w} \quad (21)$$

Based on Equation 21, the economic efficiency of each C&D waste minimisation strategy can be assessed accordingly.

6.6. Applications of the Economic Framework

As mentioned in Chapter 3, the economic evaluation framework in this research has been developed with flexibility in mind. Specifically, the framework is intended to be applicable to in various situations and with different C&D waste types. It is, hence, necessary to demonstrate this flexibility in actual cases. Specifically, the economic evaluation framework will be implemented in two case studies to test its applicability.

In the first case study, the framework is implemented to evaluate the economics of waste minimisation/zero waste for five waste streams. This example will demonstrate the applicability of the framework to situations where multiple waste streams are present. Chapter 7 will cover this case study in detail.

On the other hand, the second case study will demonstrate how the framework can be used to evaluate the economics of minimising one individual waste stream. This case study will be covered in Chapter 8.

By demonstrating that the economic evaluation framework can be applied to many different waste streams, the study reported in this thesis can show that the framework developed here is applicable to C&D waste in New Zealand.

Further, interviews with construction professionals revealed that 85% of interviewees believed a cost of landfilling C&D waste to be \$150 per tonne would be an appropriate threshold to deter construction from disposing off C&D waste while at the same time motivating the New Zealand construction industry to take waste minimisation seriously. In this study, the validity of this claim will be tested by means of the economic evaluation framework. Specifically, a cost figure of \$150 per tonne for landfill charges will be applied throughout the economic modelling process. It is anticipated that by

understanding this variable, appropriate strategies can be subsequently developed to facilitate a successful C&D waste minimisation programme in New Zealand.

6.7. Conclusion

This chapter has offered detailed discussions on the theoretical economic evaluation framework to be used in this study. This framework has been developed from the ground up using qualitative information provided by experienced construction professionals in New Zealand as a basis. Calculations for economic modelling were developed accordingly. As a result, the framework developed in this study is appropriate to New Zealand construction. Further, this framework is flexible and can be used to evaluate the economics of C&D waste minimisation for different streams.

To demonstrate its applicability to the various C&D waste stream, this framework will be applied to two case studies. Chapter 7 will discuss how the framework can be used to evaluate the minimisation of an aggregated waste stream in a new construction project. Chapter 8 will describe how the framework can be used to evaluate the minimisation of a single waste stream in a refurbishment project: brick waste.

CHAPTER 7 – CASE STUDY ONE
ECONOMIC EVALUATION OF MINIMISING MULTIPLE C&D
WASTE STREAMS

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This chapter demonstrates the application of the economic framework described in Chapter 5. The economic framework is applied to a wide range of C&D waste streams in a new-build project. The waste streams considered are divided into two categories: demolition waste and construction waste.

In the first category, waste considered includes Asbestos-contaminated waste, concrete and scrap metals. While construction waste includes plasterboard, timber, polyester materials, steel, cardboard, hardfill, plastic, glass and other general waste.

The waste data sets for this case study were provided by the specialist demolition/waste management contractor and by the main contractor, respectively. The data sets are actual accounts for this project and it will be used for the economic evaluation of waste minimisation strategies, including zero waste, for this case study.

As argued in Chapter 5, the economic evaluation framework focuses on the design stage of the project. However, for completeness, construction will also be included in modelling process and briefly mentioned in the analysis. This chapter also explore the 'design-out-waste' component to understand its economic values to the client.

7.1. Case Study Overview

The case study considered in this chapter involves the development of a new education centre for a major Auckland-based education provider. This chapter will evaluate the economics of waste minimisation strategies associated with this development using the framework developed in Chapter 6.

7.1.1. Project Background

The building is located in the Auckland Central Business District (CBD). Auckland CBD is the primary business and education district in Auckland Central, with high concentration of education providers.

This was a complex project. First, there was a limited working space available for this project. This is mainly due to the fact it is based in the Auckland CBD amid the high density of surrounding office and apartment buildings. This means the work carried out onsite during construction was strictly confined to the site boundary only.

The second challenge in this project was the fact that the building is in proximity to a number of residential apartment buildings. This means careful planning was needed to ensure the work onsite did not greatly disturb the daily lives of the people living within the apartment buildings. Specifically, it was found that noise and dust pollution could be the main issue during construction. Therefore, the contractor took appropriate steps to ensure the minimum disturbances to people's lives was achieved.

Finally, due to its central location, there was, and still is, a high traffic volume in the area surrounding the site. This presented a significant logistical challenge. This problem required the project team to undertake significant planning and develop execution systems to ensure materials can be delivered to, and waste can be taken from, site in an efficient and timely manner.

Once constructed, the building has a total floor area of 20,000 m².

7.1.2. Design Costs

The client indicated that the project budget was \$90 million while construction cost for the project was \$74 million, meaning construction cost makes up 82% of the total project cost.

Using the New Zealand Institute of Architect’s Guide to Architects’ Services, NZIA 2007 1ST EDITION, the architect’s fee for this project can be estimated to be 5% of the project cost (NZIA, 2007).

Using the Fee Guidelines for Consulting Engineering Services January 2004 – 1st edition, the fees for the following engineering services can be estimated (ACENZ & IPENZ, 2004). According to the Guideline, the consulting fees for this project are based on the total contract price and consist of the sum of two parts: design percentage fee and construction percentage fee. As shown in Table 14 below the average consulting fees for engineering services is 11% of the project budget.

Table 14: Design Fee Breakdown

Engineer	Design Fee as Percentage of Project Budget	Design Fee as Percentage of Construction Budget	Total
Fire	5%	3%	8%
Structural	6%	3%	9%
Mechanical	9%	3%	12%
Electrical	9%	3%	12%
		Average	11%

However, in this project all engineering consulting services were undertaken by one major engineering firm. As a result, this engineering company offered a discounted fee of 7% of project value.

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As the contractor and the specialist waste management contractor are also involved in the design processes, it is anticipated that they also charge a fee for their inputs. However, since their inputs are strictly restricted to waste minimisation and constructability of the building, it can be assumed that their respective costs are minor. Because of interviews with the architects, the building contractors and the waste management contractor, it has been assumed that the design fees for contractor and waste management contractor are 0.52% and 0.23% of the project budget, respectively. In total, the design fee for both architectural, engineering services and waste minimisation services consists of 12.75% of the total budget of the project. Table 15 summarises assumptions and calculations. Levels 5, 6 and 7 are as per waste minimisation strategies shown in Table 10, section 6.4.3.1.

Table 15: Design Fee for Individual Profession as Percentages of Total Project Cost

ACTOR	LEVEL 5	LEVEL 6	LEVEL 7
Architect	5.00%	6.00%	6.60%
Structural Engineer	1.00%	1.20%	1.32%
Geotechnical Engineer	1.00%	1.20%	1.32%
Mechanical Engineer	2.50%	3.00%	3.30%
HVAC Engineer	2.50%	3.00%	3.30%
Contractor	0.52%	0.62%	0.69%
Waste Management Contractor	0.23%	0.28%	0.30%
SUM	12.75%	15.3%	16.8%

As mentioned in Section 6.5.2, a waste minimisation strategy consists of a very small part of the project budget, ranging between 0.1% - 0,5 % of project budget. In this case study, it has been assumed that the waste management cost consists of only 0.1% of the total project budget. This is purely for the purpose of evaluating the economics of waste minimisation strategies.

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This means the economic considerations for the entire project consist of four major areas: demolition, design, construction and waste minimisation strategy. Since the costs as percentages for the latter three considerations are known, the cost for demolition can be calculated as 5.03% of the total project budget.

Table 16: Design Fees as Percentages of Project Budget

Component	Percentage of Project Budget	Cost
Design	12.75%	\$11,475,000.00
Demolition	5.03%	\$4,527,000.00
Construction work	82%	\$74,000,000.00
Waste Minimisation Strategy	0.10%	\$90,000.00

7.1.3. Design-out-waste Cost

For any waste minimisation strategy to succeed, there needs to be considerations for designing out waste during the design process. Information on designing out waste is extensive and can be found in guidelines such as the WRAP documentation. However, there is a lack of information of the cost associated with design-out-waste considerations in the design stage. Although it is possible to estimate the design-out-waste component in the design process, by doing so in this study would mean the scope of the research will be expanded significantly. Therefore, for the purpose of this research, an assumption is made for the cost of design-out-waste component.

As per Section 6.5.2, the cost for the design-out-waste component is estimated to be 0.5% of the total design fee charged to the building owner (i.e. 'the client'). This figure is consistent with the interview findings while catering for a modelling purposes of this research.

7.1.4. C&D Waste Breakdown

As the framework developed in this research aims to evaluate the economics of C&D waste this case study, it is essential to include both construction and demolition waste in this chapter.

Demolition waste was provided by the specialist demolition and demolition waste management specialist for this project. It was informed by the demolition company that they managed to recycle 88% of all demolition waste for this job. The breakdown of demolition waste is given in Table below.

Table 17: Demolition Waste Breakdown

Waste stream	Amount (tonne)
Asbestos contaminated debris/waste	206.78
Demolition concrete rubble for land erosion protection at Puketutu	750
Demolition concrete rubble recycled at Meremere	1,790
Demolition concrete rubble disposed at Swanson Cleanfill	150
Staff refuse disposed at Redvale	3
Steel recycled as scrap at Meremere	149
Non-ferrous recycled as scrap to Meremere	6
Asbestos contaminated waste water/sludge by Chemwaste	4.72
Total	3,059.5

On the other hand, the construction waste was made available to this research by the main contractor for this project. It was informed by the contractor that 78% of all construction waste was recycled by its specialist waste management subcontractors. The breakdown of construction waste is given in Table 18 below.

Table 18: Construction Waste Breakdown

	Weight(t)	Gib	Timber	Poly	Steel	Cardboard	Hardfill	Plastic	General
Totals		10%	48%		1%	1%	4%		36%
Weight	470.61	47.69	244.61	0.05	2.71	1.13	20.84	0.70	102.88

Both data sets show that for both demolition and construction processes a significant amount of waste was diverted from landfills. The rates of recycling of both construction and demolition waste were high (78% and 88%, respectively). This reflects the waste minimisation-focused nature of this project. Further, through this project, the client wishes to promote demonstrate 'sustainability'-driven design and waste minimisation is achievable in large education facility projects.

7.2. Benefit Assumptions

The client in this project aimed to provide world-class education to their students. They require modern teaching facilities to match such ambition. This project is part of the client's long-term development plan and was developed with significant sustainability considerations in mind. Upon completion, the building became one of the education provider's main landmarks in their City Campus. As a result, the client achieved significant values from this development.

7.2.1. Direct Benefits

This project has helped the client to significantly expand their total gross and net floor area by compared to their old building. It has been reported that the new building has contributed to an increase of the total campus area by 25%. The new building has allowed the client to increase their teaching and research capacities with the inclusion of a screen and television studio, motion capture and Chroma key studio, performance studio, radio station, sound and edit suites, digital media computer labs, and a brand-new media centre.

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In addition, it has been reported that over the life of the building, the costs for maintenance and operation are expected to be relatively low for its size. This is because the building has been fitted with low impact mechanical and electrical systems as well as the use of long-life materials during construction.

Further, the building has offered the client opportunities to receive additional income streams from leasing space on the ground floor to retailers who wish to serve the client's staff and students.

Finally, by undertaking such a large-scale sustainability-focused project, the client has an opportunity to enhance their reputations as a young and innovative organisation.

7.2.2. Valuing Client's Benefits

As can be seen, this project has shown there are significant benefits that the client can derive from. Some benefits can have direct impacts on the client's operations such as potential earnings from leasing spaces or the increased teaching and learning spaces. While other benefits such as increased reputation can be difficult to quantify. Overall, each of the above benefits can be of certain values to the client. However, none of these values were quantified by the client.

Therefore, for this study, an assumption regarding the economics of these benefits has been made. One of the client's representatives reported an estimated intangible economic benefit achieved by the client one year after the project completion to be between \$100,000 and \$500,000. For the modelling purposes, this research uses the median value of the intangible benefits, i.e. \$300,000. This monetised intangible benefit is sufficient for the economic modelling in this research.

7.3. Economic Calculations

The economic framework proposed in Chapter 6 is flexible because individual waste stream can be modelled either separately or aggregately. In other words, if information, such as cost or tonnage, for a waste streams is known (or estimated), the necessary calculations can be made separately; and then added together to obtain the result for a component of such an individual waste stream. However, if not all information about a waste stream is known or estimated, aggregated information can be used for calculations instead. In this research, the aggregated information comes in the form of average values. Although there are many ways to aggregate the cost and/or tonnage information, this research chooses average value as a preferred method for modelling purposes.

There are several waste streams considered in this research as outlined in Section 7.1.4 above. Although the breakdown of the waste during construction is detailed and informative, the breakdown of waste during demolition is not. Waste breakdown during demolition tends to focus on concrete waste. As a result, there is a lack of information in other demolition waste streams (such as glass, or plasterboard waste). The lack of information here means that an aggregated estimation method may be more appropriate than individual calculation method. This is because the aggregated estimation method will reduce unnecessary (and potentially inaccurate) assumptions regarding waste streams such as plasterboard and glass.

Based on the above analysis, it was decided that the aggregated estimation method is used in this case study.

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To ensure consistency was maintained throughout the case study, the cost components associated with materials and waste would also be aggregated.

The costs of new materials were first obtained from various sources including Laurie Forestry for timber (Laurie, 2016), Rawlinsons New Zealand Construction Handbook 2011 Edition (plasterboards) and the New Zealand Heavy Engineering Research Association and MetalCorp for steel and scrap metals (HERA, 2010; MetalCorp, 2016). Subsequently such costs were averaged to obtain aggregated values. This is shown in the table below:

Table 19: Costs of New Materials

Material	Cost (\$/tonne)	Average Cost (\$/tonne)
Plasterboard	\$360	\$316.67
Timber	\$140	
Steel	\$1400	
Cardboard	N/A (\$0)	
Poly	N/A (\$0)	
Plastic	N/A (\$0)	

For plasterboards, it was assumed that is the unit cost of each plasterboard sheet is NZD\$10. Given that a standard-sized plasterboard sheet weighs 28.08kg, meaning a tonne of plasterboard consists of 36 sheets and has a unit cost of \$360 per tonne.

Similarly, cost information regarding recycled and/or reused materials was obtained through specialist waste management companies and material manufacturers as well as publicly available information from the Ministry for the Environment's website (MfE, 2008) and MetalCorp website (MetalCorp, 2016). The aggregated cost for recycled

Plasterboard, Timber, Steel, Cardboard/Paper, Glass and Plastic is estimated to be \$115 per tonne.

7.4. Unit Cost Calculations

References for unit cost calculations come from a few sources, including Rawlinsons New Zealand Construction Handbook 2011 Edition and feedback from practicing professionals in New Zealand construction.

7.4.1. Base Rates for Calculations

The information obtained from Rawlinsons includes charge-out rate for machinery and labour, average fuel capacity of machinery and cost for diesel fuel (Rawlinsons, 2011).

This information is shown in the Table 20 below:

Table 20: Charge-out Rates for Machinery

Description	Figure	Unit
Charge-out rate per machine (incl. labour)	\$ 120.00	\$/hour
Average Fuel capacity of machine	450	L
Diesel fuel (based on 25L per hour)	3	\$/L

On the other hand, the specialist demolition contractor provided specific information around haulage and carting of waste materials as shown in the Table below.

Table 21: Haulage Charge

Description	Figure	Unit
Haulage rate	\$5.00	\$/km
Haulage capacity	20.00	tonne per skip
Average loading factor (for waste)	1.5	N/A

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From the information obtained from these two sources, several important unit costs could be estimated. These unit costs are unit cost of waste collection, unit cost of sorting waste, unit cost of recycling waste, unit cost of reusing waste and unit cost of energy used. The following sections will discuss the derivations of these unit costs.

7.4.2. Unit Cost of Collecting Waste

In this research, Google Maps was used to track and estimate distances from the construction site to various waste landfill and cleanfill sites. The research found that the average distance travel from site to waste disposal sites (d) is 60 kilometres. Given the haulage rate (hr) is \$5 per kilometre and a loading factor (lf) of 1.5, the cost of haulage per trip (H) is:

$$H = d \times hr \times lf = 60 \text{ (km)} \times 5 \text{ (\$/km)} \times 1.5 = \$450 \text{ (\$)}$$

Hence the unit cost of waste collection is (U_c) is a division of haulage cost per trip (H) by the truck capacity (c), this gives:

$$U_c = \frac{H}{c} = \frac{\$450}{20 \text{ (tonnes)}} = \$22.50 \text{ (\$/tonne)}$$

7.4.3. Unit Cost of Sorting Waste

To process 3530.11 tonnes of C&D waste in this project, this research assumes there needs to be 15 machines (Ma) based on feedback from the waste management contractor. These machines include trucks and specialised machinery that process waste at landfill.

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According to Rawlinsons, the average charge-out rate (Cr) for machinery with associated labour (including driver/operator) is \$120 per hour. Hence, the total charge-out rate (TCr) for 15 machines is:

$$TCr = Ma \times Cr = 15 \times \$120 = \$1800 (\$/hour)$$

Suppose it takes half an hour (Ts) to sort one 20-tonne capacity skip bin full of waste, the total time (T) taken to sort out all 3530.11 tonnes of waste is:

$$T = \frac{w \times Ts}{c} = \frac{3530.11 \text{ (tonnes)} \times 0.5 \text{ (hours)}}{20 \text{ (tonnes)}} = 89 \text{ (hours)}$$

This research assumes that the waste sorting rate (Rs) is 90%. This figure is reasonable, as this is a waste minimisation-focused project. As such, there was a strong emphasis on waste processing. This assumption means that a majority of the C&D waste produced by the project was sorted either onsite or off-site. Based on this assumption, a total of waste sorted (Ws) is:

$$Ws = w \times 90\% = 3530.11 \times 90\% = 3,177.099 \text{ (tonnes)}$$

Therefore, the unit cost of waste sorting is:

$$Us = \frac{TCr \times T}{Ws} = \frac{1800 \left(\frac{\$}{hour} \right) \times 89 \text{ (hours)}}{3,177.099 \text{ (tonnes)}} = \$50.42 (\$/tonne)$$

It must be noted that although a C&D waste sorting rate in this project was around 90%, not all sorted waste was reusable or recyclable and thus residual waste was still present. As shown in section 7.4.4 below, a recycle rate of C&D waste in this project was around 78% only.

7.4.4. Unit Cost of Recycling and Reusing Waste

The main contractor reported that in this project the final recycling rate of C&D waste was around 78%. As a result, the recycling rate (RR) of 78% is used in this study's economic modelling.

This means the total waste recycled (SM) is:

$$SM = w \times RR = 3530.11 \text{ (tonnes)} \times 78\% = 2753.4858 \text{ (tonnes)}$$

Assuming it takes 1 hour to process and recycle C&D waste, the total hours (Tr) needed to process and recycle waste is:

$$Tr = SM \times 1 = 2753.49 \text{ (tonnes)} \times 1 \text{ (hour/tonne)} = 2753.49 \text{ (hours)}$$

Therefore, the unit cost of recycling is:

$$U_{rc} = \frac{Tr \times Cr}{SM} = \frac{2753.49 \text{ (hours)} \times 120 \text{ (\$/hour)}}{2753.4858 \text{ (tonnes)}} = \$120 \text{ (\$/tonne)}$$

Calculation for reusing waste is similar to that of recycling waste. As a result, the unit cost of reusing waste is $U_{rw} = \$120 \text{ (\$/tonne)}$

7.4.5. Unit Cost of Energy

The total trips (T_{trip}) required to cart away the project's C&D waste is

$$T_{trip} = \frac{w}{c} = \frac{3530.11 \text{ (tonnes)}}{20 \text{ (tonnes/trucks)}} = 177 \text{ (trucks or trips)}$$

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For the purpose of modelling, each of the above 177 trucks or trips can be treated as a unit of machinery. Combine with the machinery required for processing waste, the total units of machinery required for the entire project is:

$$T_{\text{machine}} = T_{\text{trip}} + M_a = 177 + 15 = 192 \text{ (machines)}$$

Based on Rawlinsons' information, the average fuel capacity (F) of a large machine/truck is 450 litres and the cost of diesel fuel (cf) is \$3 per litre (Rawlinsons, 2011). This means the unit cost of energy used by all machinery is:

$$U_{\text{en}} = \frac{T_{\text{machine}} \times F \times cf}{w} = \frac{192 \text{ (machines)} \times 450 \text{ (L)} \times 3 \left(\frac{\$}{\text{L}}\right)}{3,177.099 \text{ (tonnes)}}$$

$$U_{\text{en}} = \$73.43 \text{ (\$/tonne)}$$

It has been shown in literature that, significant investments must be spent to achieve zero waste. By doing so, it is anticipated that the processing and energy costs will also increase (Phillips, 2012). For this reason, it has been assumed in this study that the energy and processing costs will be increased by 25% and 50% for Levels 6 and Level 7 strategies, respectively, compared to the baseline strategy (Level 5).

7.4.6. Design-out-waste Costs

As mentioned in Chapter 6, in this project, at least 78% of C&D waste was diverted from landfill. This was an aggregated figure provided by the contractor and demolition sub-contractor. This study also considers eight strategies ranging from landfilling waste to zero waste. From a modelling perspective, it is appropriate to have Level 5 waste

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minimisation strategy as the baseline for analysis. This is because Level 5 is the beginning of the 70% mark of waste reduction. Given the actual waste reduction rate of the project is between 78% and 95% (for construction waste and demolition waste respectively), this baseline is appropriate.

It was assumed in Chapter 6 that the design cost increases proportionally to the increase in waste reduction level. The rates of increase are 15% and 30% for increases from Level 5 to Level 7 and from Level 6 to Level 7, respectively. The total design cost for each strategy are shown in Table 22:

Table 22: Design Cost for Each Strategy

Level	5	6	7
Design Cost	\$ 11,475,000.00	\$ 13,770,000.00	\$ 15,147,000.00

Further, since the design-out-waste component consists of 0.5% of the total design cost (see Section 7.1.3), the cost of this component for each level of waste minimisation is presented in Table below.

Table 23: Design-Out-Waste Cost for Each Strategy

Level	5	6	7
Design-out-waste Cost	\$ 57,375.00	\$ 68,850.00	\$ 75,735.00

7.5. Results of the Economic Evaluation

In this study, Microsoft Excel™ is the chosen economic modelling tool. This choice is adequate as Microsoft Excel™ contains many powerful built-in mathematical packages for modelling purposes. All waste minimisation strategies are modelled in Microsoft

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Excel™. All modelling outputs are also analysed in Microsoft Excel™. This ensures the consistency of the study.

With the all necessary unit costs established in the Section above, the economic modelling framework can be used to evaluate the waste minimisation strategies.

In this case study, four waste minimisation strategies will be considered. They are Level 1 (disposing of waste to landfill); Level 5 (baseline analysis); Level 6 (minimising waste by 71%-95%) and Level 7 (zero waste). The Level 5 waste minimisation strategy is the baseline level for analysis as per discussion above. On the other hand, the inclusion of Level 0 waste strategy is necessary for comparison purposes. By including Level 0 C&D waste strategy in the study, this research can compare the economics of landfilling waste with the economics of other waste minimisation strategies.

Using the formulations established in Chapter 6, results for each strategy can be obtained as shown in Table 24 below.

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BENEFIT COMPONENT	LEVEL 1	LEVEL 5	LEVEL 6	LEVEL 7
Intangible benefits	\$300,000.00	\$300,000.00	\$300,000.00	\$300,000.00
Cost saving from reusing materials	\$ -	\$181,538.91	\$277,647.74	\$355,958.64
Cost saving from recycling materials	\$ -	\$181,538.91	\$277,647.74	\$355,958.64
Cost saving from non-disposal of materials	\$ -	\$270,053.42	\$413,022.87	\$529,516.50
Revenue from selling recycled/repurposed materials	\$ -	\$207,040.95	\$316,650.87	\$405,962.65
Total cost saving	\$300,000.00	\$1,140,172.19	\$1,584,969.22	\$1,947,396.43
COST COMPONENT	LEVEL 1	LEVEL 5	LEVEL 6	LEVEL 7
Cost of design out waste	0	\$57,375.00	\$68,850.00	\$75,735.00
Cost of waste strategy	\$90,000.00	\$90,000.00	\$90,000.00	\$90,000.00
Cost of reusing waste	0	\$ 216,042.73	\$ 330,418.30	\$ 423,613.20
Cost of energy used in repurposing C&D waste	0	\$66,100.07	\$126,376.79	\$194,411.98
Cost of recycling waste	0	\$ 216,042.73	\$ 330,418.30	\$ 423,613.20
Cost of energy used in recycling C&D waste	0	\$66,100.07	\$126,376.79	\$194,411.98
Cost of waste collection	\$79,427.48	\$79,427.48	\$79,427.48	\$79,427.48
Cost of waste landfill	\$529,516.50	\$259,463.09	\$116,493.63	\$ -
Cost of waste materials	\$1,117,879.93	\$547,761.17	\$245,933.59	\$ -
Total Cost of Waste	\$1,816,823.91	\$1,598,312.34	\$1,514,294.87	\$1,481,212.84
BENEFIT - COST RATIO	17%	71%	105%	131%

Table 24: Modelling Result - Case Study One

7.6. Analysis

This section provides detail analyses of the results obtained from the Section 7.5 above. Three areas that will be considered in this section:

1. The cost of waste versus the cost savings from waste minimisation
2. The cost effectiveness of waste minimisation via design-out-waste
3. The economic efficiencies of waste minimisation strategies

The first consideration is achieved by a direct comparison between the two key components of a waste minimisation strategy, namely the monetised benefits associated with a strategy versus the cost of implementing the corresponding strategy.

The second area involves a detailed analysis of the economic effects that design-out-waste can have on a waste minimisation strategy. The analysis in this area covers matters such as implications of design-out-waste in practice and potential issues associated with its implementation.

Finally, the economic efficiencies of each waste minimisation strategy is weighed against to provide a good understanding of the economic performance of each strategy. This is achieved by means of a benefit-cost ratio (BCR). The benefit-cost analysis will also help identify the waste minimisation rate which is considered the economically optimal rate for the waste minimisation in this case study.

7.6.1. Basis of Comparison

In this research, efforts have been made by the researcher to ensure consistency is maintained. For comparison purposes, necessary moderations in calculations were made to make sure costs were compared to corresponding cost savings appropriately.

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As seen in the Table 24, this research contains five cost savings components and nine cost components. Since each cost component contains two elements addressing different parts of the same component, the cost elements of a same component can be amalgamated to produce an overall cost for that component. The newly amalgamated costs can then be compared to the cost savings of the corresponding components (Table 26).

Cost savings/benefit components and their corresponding cost components are shown in Table 25 below:

Table 25: Basis of Comparison Conversion

Cost Saving/Benefit	Amalgamated Cost (AC)	AC as Sum of Cost Element
Cost saving from reusing materials	Cost of reusing materials	Cost of reusing waste and Cost of energy used in repurposing C&D waste
Cost saving from recycling materials	Cost of recycling materials	Cost of recycling waste and Cost of energy used in recycling C&D waste
Cost saving from non-disposal of materials	Cost of waste collection and landfilling	Cost of waste collection and Cost of landfilling waste
Revenue from selling recycled/repurposed materials	Cost of waste materials	Cost of waste materials
Intangible benefits	Cost of design-out-waste and waste strategy	Cost of design out waste and Cost of waste strategy

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Table 26: Converted Results

LEVEL	LEVEL 1	LEVEL 5	LEVEL 6	LEVEL 7
Benefit Component				
Intangible benefits	\$300,000	\$300,000	\$300,000	\$300,000
Cost saving from reusing materials	\$ -	\$181,539	\$277,647	\$355,958
Cost saving from recycling materials	\$ -	\$181,539	\$277,647	\$355,958
Cost saving from non-disposal of materials	\$ -	\$270,053	\$413,023	\$529,516
Revenue from selling recycled	\$ -	\$207,040	\$316,650	\$405,962
Total Cost Savings/Benefits	\$300,000.00	\$1,140,172	\$1,584,969	\$1,947,396
Cost Component				
Cost of design out waste + waste strategy	\$90,000	\$147,375	\$158,850	\$165,735
Cost of reusing materials	\$ -	\$282,142	\$456,795	\$618,025
Cost of recycling materials	\$ -	\$282,142	\$456,795	\$618,025
Cost of waste collection + landfilling	\$ 608,944	\$338,890	\$195,921	\$79,427
Cost of waste materials	\$1,117,879	\$547,761	\$245,933	\$ -
Total Cost of Waste	\$1,816,823	\$1,598,312	\$1,514,294	\$1,481,212
BENEFIT - COST RATIO	17%	71%	105%	131%

As shown in Table 26, the cost of waste decreases when rigorous waste minimisation strategies are implemented; while at the same time, cost savings increase proportionally. This results in an increasing benefit-cost ratio across four strategies considered (Levels 1, 5, 6 and 7).

7.6.2. Costs versus Savings

The cost saving components of each waste minimisation strategy was charted against their respective cost components as in Figure 5. Sections 7.6.2.1 – 7.6.2.4 will explain this figure in more detail.

COST SAVING VERSUS COST OF WASTE STRATEGIES

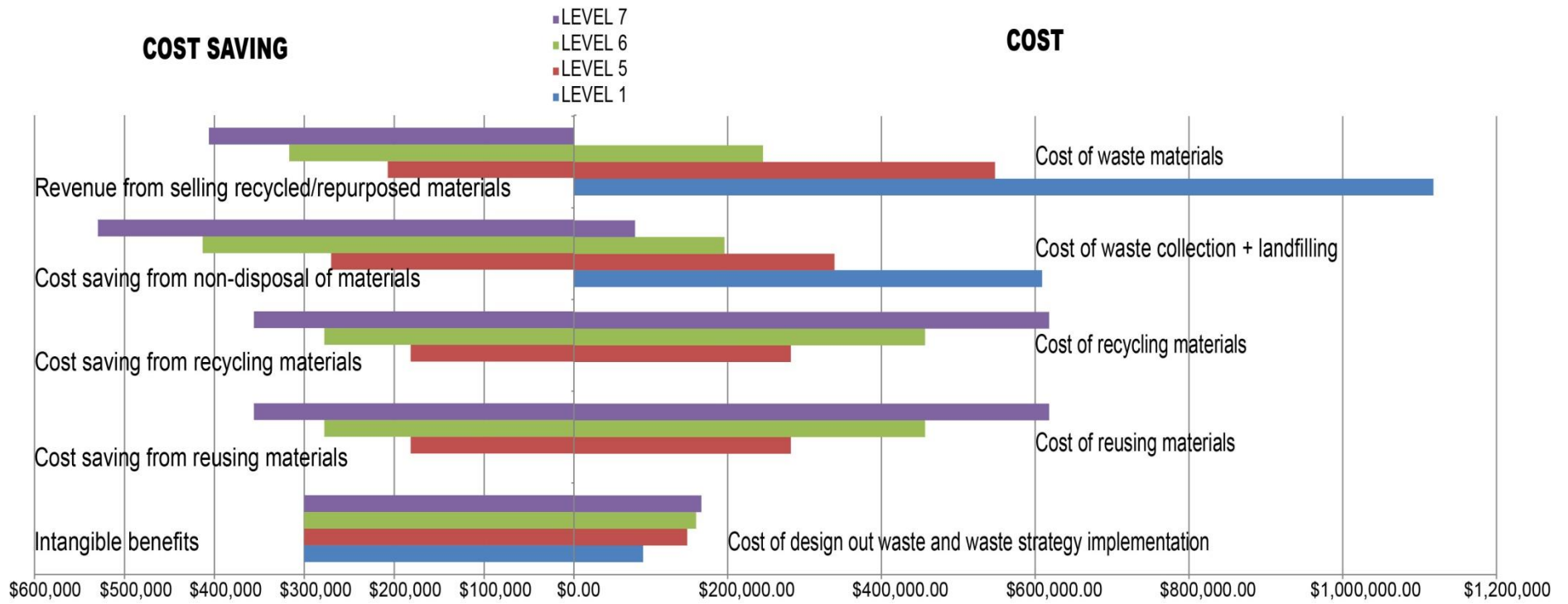


Figure 5: Tornado Chart of Benefits and Costs - Case Study One

7.6.2.1. Analysis of 'Do-Nothing' Waste Strategy (Level 1)

Generally, the cost of waste in Level 1 waste strategy is most significant among the four waste strategies considered. Both 'cost of waste materials' and 'cost of waste collection and landfilling' in this strategy remain highest among the four strategies considered.

At the same time, as C&D waste is being disposed of in landfill, there is no cost for recycling and repurposing materials. Perhaps this is the only upside in this strategy. Despite this, the total cost of waste for this strategy remains significantly high (second only to the zero-waste strategy). This high cost of waste shows that this strategy may not be cost effective for the client since it does not offer the client any potential benefits like the other strategies can offer.

There is no cost saving offered to the client in this waste strategy because when the client decides to send the waste materials to landfill, they have, in effect, buried any potential cost savings that can be derived such 'waste'. For instance, the client cannot on-sell any processed materials to the secondary markets in this strategy in order to offset the costs of purchasing the original materials.

A combination of a significantly high cost and low returns on investment shows that the 'do-nothing' strategy (Level 1) does not, and cannot, offer the client an economical waste minimisation strategy.

From the economic perspective, this strategy is not economically sound. A benefit - cost ratio of 17% shows Level 1 strategy can offer a relatively low level of economic efficiency, thus potentially a low return on investment. Assuming the client is rational and makes investments which maximises their utilities, from an economic perspective it is likely that they would explore other alternatives before revisit this strategy.

7.6.2.2. Analysis of Level 5 Waste Minimisation Strategy

As shown in Figure 5, the cost of waste materials for this strategy is slightly higher than the potential revenues that can be derived from it. Unlike Level 1 strategy, the baseline strategy offers the client more cost savings in all five benefit components. The cost savings for four benefit components in this strategy (reuse, recycle, non-disposal and resale) are \$181,538.91, \$181,538.91, \$270,053.42 and \$207,040.95. However, the costs for the respective cost components remain higher than the cost savings for these four components (\$282,142.80, \$282,142.80, \$338,890.57 and \$547,761.17, respectively). The only exception to this rule is in the last component, where value of intangible benefits is higher than that of the corresponding costs (\$300,000.00 compared to \$147,375.00).

Although the cost savings in this strategy are still modest, the higher values in benefit compared to the Level 1 waste strategy show a significant improvement in terms of values this strategy can offer to the client. Specifically, the baseline waste minimisation strategy shows a high degree of economic efficiency with BCR equalling 71%, compared to Level 1's BCR of 17%. This means that economically this strategy performs better than the Level 1 waste strategy.

7.6.2.3. Analysis of Level 6 Waste Minimisation Strategy

In this strategy, the levels of cost savings have improved significantly compared to the two previous strategies. Apart from the reuse and recycle components, all three other cost saving components show higher values than those in respective cost components. This is because more waste is being diverted from landfill. As less waste end up in landfills, the client pays less to dispose of waste there. Given that the cost of landfilling is \$150 per tonne, the client can save significant amount in this manner.

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As 'waste' is now becoming precursor materials for industrial processing, i.e. 'resources', it can be resold or traded in secondary markets to help recuperate some of the costs the client has first paid for the materials.

The reason the costs of recycling and repurposing materials remain high is due to two reasons. First, as shown in Chapter 6, there is an assumption that the energy costs associated with recycling operations at Level 6 waste minimisation strategy will increase by 25% compared to those in Level 1 and Level 5 waste strategies. This means that the energy costs in this strategy are much higher than those in previous strategies.

Second, as waste minimisation strategies become more rigorous, more 'potential resources' (previously known as 'waste') become available. That means there may be an increase in demand to process and turn these 'potential resources' into usable products. In turn, this means that the cost for recycling and repurposing operations must increase accordingly. The combined effect of these two cost elements means that the overall costs for processing waste remain high.

Despite the high processing costs, Level 6 waste minimisation strategy has shown a significant economic efficiency; with the benefit-cost ratio remaining over 100%. This high economic efficiency shows that even with a moderately high waste minimisation rate (78%), the project has provided the client a significant value for money. It also shows that it is worth undertaking a waste minimisation; but with waste minimisation rate of at least 78% to ensure an appropriate level of returns on investment.

7.6.2.4. Analysis of Zero Waste Strategy – Level 7

Zero waste is the ultimate waste minimisation strategy considered in this research. As shown in the economic framework developed in this research, in this strategy 100% of 'waste' is utilised as 'resources' for further industrial processes. In other words, this strategy achieves total efficiency in usage of all C&D materials.

To adhere to this ideal, the economic model for the zero waste strategy assumes a waste reduction rate 100% for this strategy. This means in this strategy there is no residual waste, as all 'waste' is recycled, reused or repurposed for other uses. Under this assumption, the cost of waste materials is zero, since no material is wasted under this strategy. Similarly, there is no cost of disposal, as no waste will end up in landfill. The only cost that remains is the cost of collection, as there is still a need to collect the waste (or new 'resources') for further industrial processing.

As in the case of Level 6 waste minimisation strategy, the cost of recycling and the cost of reusing outweigh the corresponding benefits. This is mainly due to the increases in both recycling/reusing costs and energy costs. As all 'waste' are now 'resources' which need to be processed, the processing costs must increase significantly. At the same time, under an assumption in Chapter 6, the energy cost associated with such industrial operations also increase by 50% compared to that in Level 1 and Level 5 waste strategy. Together, these two cost elements contribute to the significant increases in recycling and reusing cost components of the zero waste strategy.

It can be observed from Figure 5 that the design cost for the zero waste strategy is highest among all strategies considered. The high design cost here is due to two elements: the time and effort required by designers to ensure no waste is generated;

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and the high cost of compliance associated with the rigorous waste minimisation practices required by the zero-waste strategy.

In the first element, to achieve zero waste, it is anticipated that the design team (including architects, engineers and contractors) must spend considerable time and effort to design systems that generates no waste during construction. It is no doubt that such a system, if it exists, would be highly complex. This time and effort spent on design also means that the cost associated with design will likely increase.

Once the waste minimisation system is designed, it must be implemented in order to achieve the 'zero waste' objective. It is contended that due to construction's fragmented nature, the implementation of such a system would be highly complicated. Therefore, there will be a need for a rigorous implementation plan as well as associated compliance strategy. This requirement means that the cost associated with a waste minimisation strategy will likely increase as well.

However, the combined cost of these two elements is shown in Figure 5 to be relatively low compared to their associated benefits, the monetised intangible benefits. This means that despite the increases in design and compliance costs, the client can derive much more significant values from the zero-waste strategy. In fact, this strategy has shown to be the most economically efficient strategy, with BCR remaining well above the 130% mark. The comparison of economic efficiencies between waste minimisation strategies will be discussed in detail in Section 7.7.

7.6.3. Analysis of Design-out-Waste

The design-out-waste cost comprises a small portion (0.5%) of the total design cost of this project. However, as in Chapter 6, the rate of design cost increases between different waste minimisation levels are:

Table 27: Assumed Increases of Design Fees (Duplicate of Table 12)

From strategy to strategy	Rate of design fee increase
1 TO 2	20%
2 TO 3	10%
3 TO 4	10%
4 TO 5	10%
5 TO 6	15%
6 TO 7	30%

Given that the baseline waste minimisation strategy in this case study is Level 5, the breakdown of design cost and the cost of the design-out-waste component can be calculated and presented in Table 28.

Table 28: Design Cost and Design-Out-Waste Cost for Each Strategy

Level	5	6	7
Design Cost	\$11,475,000.00	\$ 3,770,000.00	\$15,147,000.00
Design-out-waste Cost	\$ 57,375.00	\$ 68,850.00	\$ 75,735.00

As the design cost increases, the cost of design-out-waste component also increases proportionally. This is a response the increased complexity in waste minimisation requirements. As more waste is being minimised, the designers must find more innovative ways to help meet this goal. This means the designers must collaborate with other parties, including contractors and material manufacturers, to research and incorporate durable materials or materials that can be reused / recycled after their useful lives in the design. The increased cost is a reflection of the increased efforts and

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time spent on researching, understanding and designing systems that can offer minimal wastages.

7.6.3.1. Design Participants’ Learnings

As outlined above, the design-out-waste is complex and time consuming process which involves participations of different parties. This means the participants in this process must also get paid. And their payments should be proportional to the increased complexity. The cost breakdown for each actor in design (Table 29) and design-out-waste (Table 30) can be calculated.

Table 29: Design Cost Breakdown for Each Profession

ACTOR	LEVEL 5	LEVEL 6	LEVEL 7
Architect	\$ 4,500,000.00	\$ 5,400,000.00	\$ 5,940,000.00
Structural Engineer	\$ 900,000.00	\$ 1,080,000.00	\$ 1,188,000.00
Geotechnical Engineer	\$ 900,000.00	\$ 1,080,000.00	\$ 1,188,000.00
Mechanical Engineer	\$ 2,250,000.00	\$ 2,700,000.00	\$ 2,970,000.00
HVAC Engineer	\$ 2,250,000.00	\$ 2,700,000.00	\$ 2,970,000.00
Contractor	\$ 468,000.00	\$ 561,600.00	\$ 617,760.00
Waste Management Contractor	\$ 207,000.00	\$ 248,400.00	\$ 273,240.00
SUM	\$ 11,475,000.00	\$13,770,000.00	\$ 15,147,000.00

Table 30: Design-Out-Waste Cost Breakdown for Each Profession

ACTOR	LEVEL 5	LEVEL 6	LEVEL 7
Architect	\$ 22,500.00	\$ 27,000.00	\$ 29,700.00
Structural Engineer	\$ 4,500.00	\$ 5,400.00	\$ 5,940.00
Geotechnical Engineer	\$ 4,500.00	\$ 5,400.00	\$ 5,940.00
Mechanical Engineer	\$ 11,250.00	\$ 13,500.00	\$ 14,850.00
HVAC Engineer	\$ 11,250.00	\$ 13,500.00	\$ 14,850.00
Contractor	\$ 2,340.00	\$ 2,808.00	\$ 3,088.80

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Waste Management Contractor	\$ 1,035.00	\$ 1,242.00	\$ 1,366.20
SUM	\$ 57,375.00	\$ 68,850.00	\$ 75,735.00

As can be seen in Table 29 and Table 30, everyone involved in the design and design-out-waste processes get paid well. Aside from traditional designers such as architects and engineers, contractors also make good money for their involvement in the design stage. From an investment perspective, it is a good idea and good practice to get the contractors involved early in the design process for two reasons. First, as contractors get involved in the design stage, they can improve the overall constructability of the project with their practical inputs. In a way, this will reduce the process waste significantly due to prompt communication between the designers and the contractors.

Second, if the project has the participation of contractor, it is likely that contractor take ownership of their work. This in turns means the contractor will likely take proactive actions to reduce and minimise wastages during construction. This can be done by requiring sub-contractors to take actions to reduce and minimise waste to meet required targets. As construction is fragmented in nature, construction work onsite is often delegated or subcontracted to various parties. When the main contractor gets involved in a waste minimisation-focused project, they have the power to force subcontractors to meet waste minimisation targets set by the designers and clients. This is up to the subcontractor to ensure they have appropriately trained personnel to carry out the work while meeting waste minimisation targets. This means all commitment regarding skill training for onsite operatives rests with the subcontractors, and at subcontractors' costs. In other words, the main contractors can derive significant benefits from a waste minimisation-focused project with minimal to no downsides. Benefits to the contractors

can be tangible and intangible. Tangible benefits come from earnings from design, free training in waste minimisation while intangible benefits come from marketing exposures and improved reputation. This means the contractor can get more benefits from a waste minimisation project compared to a non-waste-focused project of a similar construction price. From an economic perspective, the contractor would be willing to get involved in, and committed to, a waste minimisation-focused building project.

7.6.3.2. Cost Implications to the Client

From the client's perspective, the investment in design can offer significant potential pay-offs. Having a good design with thorough considerations for waste can result in fewer materials being wasted in a project. This allows the client to receive significant cost savings (as in the case of Level 6 and Level 7 strategies). At the same time, the client can get significant 'soft' benefits such as improved reputation and marketing. Although it can be difficult to quantify these 'soft' or intangible benefits, they exist and are of value to the client.

Despite the fact that the design and design-out-waste costs can increase depending on the types of waste minimisation strategy, given the significant benefits that the client can get from the project, such increased costs will unlikely deter the client from a waste minimisation/zero waste strategy.

7.7. Benefit-Cost Analysis

Benefit-Cost Ratio (BCR) of each strategy is essentially the ratio of total monetised benefits and total costs. BCR assesses the economic efficiency of a strategy. In other words, it measures how returns on an investment weigh against the associated costs.

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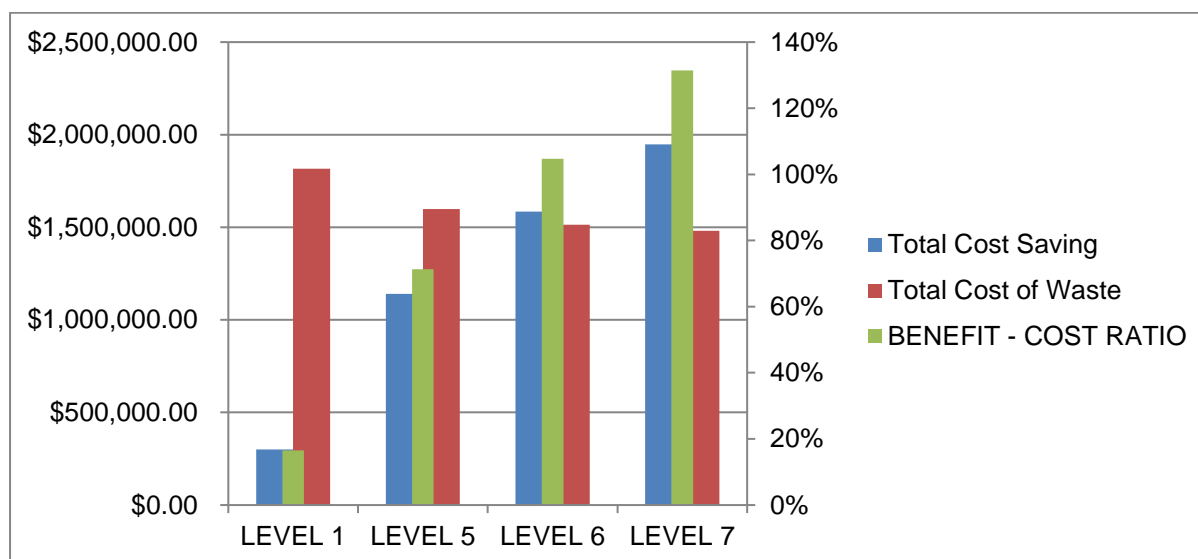
In a given economic environment, an investment with a high BCR the ratio shows such an investment is economically efficient and can offer the investor better value for money.

In this section, BCRs of all four waste minimisation strategies in this project are extracted from Table 24 and Table 26 and presented in Table 31 and Figure 6.

Table 31: BCR for Each C&D Waste Minimisation Strategy

LEVEL	1	5	6	7
Total Cost Saving	\$300,000.00	\$1,140,172	\$1,584,969	\$1,947,396
Total Cost of Waste	\$1,816,823	\$1,598,312	\$1,514,294	\$1,481,212
BENEFIT - COST RATIO	17%	71%	105%	131%

Figure 6: Presentation of Results in Case Study One



There is a trend across all four waste minimisation strategies: there is an increase in benefits and cost savings while at the same time the costs associated with the corresponding strategies are diminishing. This trend is presented in Figure 6.

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This inverse relationship between benefit and cost has resulted in the increases in BCRs from Level 1 strategy to Level 7 strategy.

7.7.1. BCR of Level 1

Of the four strategies under consideration, waste strategy Level 1 offers the lowest BCR of 17%. This strategy has the highest cost of waste but with the lowest benefits offered to client. From an investment perspective, this strategy has a low level of economic efficiency and as such it is unlikely to be implemented.

7.7.2. BCR of Level 5

The baseline waste minimisation strategy of this case study is of a relatively high order in all waste strategies considered in this research (Level 5). This means under this strategy, at least 51% of C&D waste must be reduced and diverted from landfill. This is a significant waste minimisation requirement and thus has required a significant level of investments in design and implementation. Due to a relatively high level of investment it has received, the baseline waste minimisation strategy has achieved a high degree of economic efficiency. The BCR of this strategy equals 71%. Overall, this strategy has a relatively low energy cost compared to Level 6 and Level 7 strategies. However, the costs associated with waste disposal and material waste remain higher than those of Level 6 and Level 7 strategies. Nevertheless, this strategy may still be worth considering, given its high economic efficiency level.

7.7.3. BCR of Level 6 and Level 7

Both Level 6 and Level 7 waste minimisation strategies can offer the client total efficiency (105% and 131%, respectively). In other words, these strategies can provide the client a significant value for money. It is thus worth comparing the Level 6 waste minimisation strategy and the Level 7 zero waste strategy. This comparison is useful because it can help identify an optimal waste minimisation strategy for this case.

Overall, Level 6 has a much lower cost in four main cost categories than the zero waste strategy. These categories are design-out-waste, recycling, reusing and energy used in processing waste. However, since Level 6 strategy can only reduce 78% of C&D waste, there is still a significant wastage present in this strategy. This in turns means that the costs associated with waste disposal and material waste in Level 6 strategy is much higher than those in the zero waste strategy. In fact it is these high cost components that have contributed to the higher overall cost of Level 6 compared to that of Level 7.

In a zero waste strategy there is no cost of disposal, as all 'waste' is now 'resources' for industrial processing; thus eliminating the need to dispose of waste to landfills. At the same time, the client also achieves significant increases in cost savings due to this elimination. The net effect of decreased costs and improved benefits is the BRC under this strategy has increased significantly (131% compared to 105% in Level 6 strategy). This sharp increase in BCR is due to the aggressive steps taken in minimising waste streams.

However, zero waste is an idealised concept and it is impossible to achieve total elimination of waste. As such, in reality the Level 7 waste minimisation is impractical despite its high economic efficiency yielding. On the other hand, Level 6 waste

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minimisation is achievable, and has been achieved in this actual case study. As both strategies give the client total economic efficiency, and Level 6 is more achievable than its contemporary Level 7, it is contended in this research that the Level 6 waste minimisation is the optimal strategy for this case study.

Therefore, it can be argued that it is worth undertaking a waste minimisation in this case; but the waste minimisation rate must be at least 78% to ensure an appropriate level of returns on investment.

7.8. Findings

7.8.1. Waste Strategy Level 1 – Landfilling

From the analysis sections, there is little value to the client in disposing of C&D waste to landfill. By sending waste to landfill, the client gets little economic benefit. The only benefit to the client in this strategy is savings on labour cost on site from waste segregation. However, they are still liable for a cost for disposing of such waste, meaning the client ends up paying twice for the same material. Initially they must pay for the new and virgin materials for the construction of the building. Then once some of the new materials is demoted to 'waste' during the construction process, the client must pay a fee to dispose of this waste.

Further, as landfill charges get more expensive, it makes the practice of disposing of waste an expensive option. At a landfill charge of \$150 per tonne, it has been shown that the disposal costs become a major cost component in the project. Due to this fact, the client should start to look for approaches to reduce the C&D waste output.

7.8.2. Waste Minimisation Levels 6 and 7

Unlike the 'landfill' option, the client can get significant economic advantages from higher level 'waste minimisation' strategies (Levels 6 and 7). These advantages include opportunities to save on materials (as limited wastages occur, and end up, in landfills under these strategies); opportunities to save on transportation costs (as materials can be delivered on demand, and minimal dumping trucks required under these strategies); and opportunity to on-sell the excess materials to secondary markets.

In addition, under these strategies, the client has an opportunity to engage closely with other stakeholders such as architects, engineers and contractors to manage and minimise waste. These collaborations can be explicitly expressed via penalty/incentive schemes to encourage the stakeholders to uptake waste management practices throughout the project. Since money is an important economic driver in construction, by having such a scheme could significantly increase the success rates of a waste management programme (Tam & Tam, 2008). It has been argued by Tam & Tam (2008) that an introduction of a penalty/incentive scheme can enhance the chance of achieving the project's waste minimisation goals. However, this study does not explore this avenue since it lies outside the scope of the study for the reasons outlined in Chapter 5. Instead, it has been shown in the analysis above that minimisation and zero waste strategies are viable and more economically more efficient than the 'do-nothing' strategy, i.e. landfilling waste.

Nevertheless, it has been observed by the researcher that the implementation of a penalty/incentive scheme will likely require a robust contractual agreement between project partners as well as a comprehensive waste management/waste minimisation

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plan. This means such a penalty/incentive scheme, if introduced, may increase the cost component significantly compared to the 'landfill' strategy. But as shown in the analysis above, the economic benefits offered by the 'waste minimisation' and 'zero waste' strategies can outweigh the additional administrative costs of a waste minimisation strategy. As such, there may be room to include a penalty/incentive scheme. However, since this area is outside the scope of the study, there is no way to confirm or deny this observation. This is indeed an opportunity for subsequent research to explore.

Aside from the direct economic benefits that the client can derive from waste minimisation and zero waste strategies, the client can also obtain many intangible benefits from having 'waste minimisation' and 'zero waste' strategies in their projects. These include opportunities to improve their reputations and credentials, thus increasing the opportunities to market their brand/image. In turn, the project creates an opportunity to increase the value for the education provider via highly competitive rentals to tenants. Further, the client representative has advised that the development of this education building has contributed significantly to the increased morale and productivity of staff and students.

As previously noted in Chapter 6, for the purpose of this study, an assumption on the value of intangible benefits of 'waste minimisation' and 'zero waste' strategies has been made. Specifically, the intangible benefits that the client gets from these strategies are assumed to be \$300,000.

As shown in Section 7.7.3, with such a conservative value for the intangible benefits, the client can achieve high levels of economic efficiency. Therefore, it can be concluded that there are indeed values in minimising the C&D waste in this case study.

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Specifically, both Level 6 waste minimisation and the Level 7 zero waste strategies can offer the client total economic efficiencies. This means the client has imperatives to implement either of these options. However, it has been argued in the analysis section that perhaps Level 6 waste minimisation strategy is the optimal option for the client. Therefore, the research recommends the client to choose this option.

7.8.3. Implications of landfill charge variable

The analyses above have also shown the variable 'landfill charges' can have a significant influence on the management or minimisation strategies of C&D waste. By setting the landfill charges at \$150 per tonne, this study has observed major impacts this variable has on both the cost incurred, and the benefits gained, by the client. This is because landfill charges increase, it becomes more expensive to dispose of waste.

At the same time, the client is incentivised to manage and minimise such waste due to the significant economic benefit potentials offered by such practices, including, but not limited to cost-savings and resale of excess materials. In this sense, the variable 'landfill charges' has a positive influence on the benefits obtained by the client from their waste management/waste minimisation strategies. This finding is important because it confirms the long-held belief in the New Zealand construction industry that increasing landfill charges will induce behavioural change in the industry regarding its waste minimisation.

7.8.4. Limitation

Through this case study, the research has demonstrated that the proposed framework could be used to evaluate the economics of a range of C&D waste.

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However, the weakness of this study is it currently focuses on only one fixed area: landfill fee of \$150 per tonne of waste. This makes this study one-dimensional. There are many factors that can have significant effects on the success of a waste minimisation strategy. Further, many of such factors are interlinked or inter-related. Thus, by making 'landfill fees' the one key focus, this study does not, and cannot, exhibit the true extent of the problem related to C&D waste minimisation in New Zealand. However, this chosen paradigm is necessary given the limited time and scope imposed on the study reported in this thesis. Subsequent studies can be carried out to establish other variables that have significant effects on the success of a waste minimisation strategy. This will help the industry to understand these variables better and how they can affect a zero waste aspiration in NZ construction.

7.9. Operatives in C&D Waste Minimisation

It is contended that everyone involved in the project has an important role to play to ensure a waste minimisation strategy meets its intended objectives. This section briefly discusses the roles and responsibilities of key participants. Although the focus of the discussion rests on the design phase, their respective responsibilities also extend to the construction and operation stages.

7.9.1. Client and Project Manager (client side)

These parties are owner of the building and the representative of owner, respectively. They have the interest of the owner at the centre of their actions. In a waste minimisation-focused such as this case study, both the client and the Project Manager

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would work hard to ensure a minimal amount of C&D waste was produced. This is so they can realise the significant tangible and intangible benefits as outlined above.

As a result, they would tend to be involved in all stages of the development. However, as outlined in Chapter 5, once the contract was awarded, the influence of the client and the project manager on waste minimisation would be significantly reduced. Instead, that responsibility rests with the contractor. And only through the contractor that the client and the project manager could help reduce waste.

In contrast, the client and the project manager had the greatest influence on the waste minimisation agenda at the design stage. It is at this stage that they could set targets and strategies for waste minimisation. By influencing other key participants, it is contended that a significant wastage could be potentially reduced before the construction even took place. Further, as argued in Chapter 5 and Chapter 6, the cost of waste for the client at this stage was insignificant compared to the overall project cost (and to any changes at later stages for that matter). Therefore, the client should be proactive and involved in waste minimisation right from the design stage.

7.9.2. Designers

Designers such as architects and engineers have a key role in the waste minimisation strategy. Through efficient designs, the designers could potentially help reduce wastages in the construction phase. However, each commercial design entity would have their own agendas. Therefore, to achieve a common waste minimisation goal, there is a need for the designers to work collaboratively with other participants, including the client, other designers and contractors.

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As the design stage has a potential to maximise the waste reduction, the designers must be proactive in researching, choosing and designing efficient systems that can help achieve the intended waste minimisation objective. These systems could include, but not limited to, new materials, durable materials, building technology and prefabricated components. For example, it has been shown that prefabrication can help reduce waste by up to 52% (Jaillon et al, 2009).

Further, designers should also be involved in supervision of the building construction to ensure all systems work as designed and that wastages could be minimised accordingly.

From the commercial perspective, the designer has an opportunity to earn significant more in a waste minimisation-focused project than a comparable non-waste minimisation-focused project. This is because in the former, the designer must spend significant more time to research and design appropriate systems to support the achievement of the intended waste minimisation goal. The more complex or rigorous the waste minimisation strategy becomes, the more money the designers can earn (as more hours are required to design appropriate systems). This is the commercial incentive for the designers in a waste minimisation-focused project such as this one.

7.9.3. Contractors

The contractors have a significant role in ensuring all waste minimisation goals are met during construction. This role can also extend to the design stage, although their involvements can be more limited than other participants such as the designers.

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During the design stage, the contractor can be involved to provide inputs on the constructability and areas which they think waste could be minimised. The involvement of the contractor during the design phase can provide significant value to the overall design. They can bring in with them a wealth of knowledge and experience regarding constructability and building systems. In turns this can ensure the building is functional while meeting waste minimisation targets in the construction stage.

For contractors, it is possibly at the construction phase that they have the greatest influence on waste minimisation. The contractors would be responsible for every aspect of the construction stage. This means they have the power to make sure C&D waste is properly sorted, reused or recycled. This could be done through influencing onsite operatives and subcontractors. They may have opportunities to identify areas to reduce waste further when the construction is under way.

However, from a commercial perspective there must be incentives for the contractors to undertake waste minimisation practices onsite. One such incentive is for the client to engage the contractors early and get them involved in the design stage. By being involved in the design phase, the contractors have an opportunity to earn extra incomes aside from their tendered prices. Although the money earned through this involvement may be relatively insignificant compared to the tendered prices, this early engagement allows the contractors to have a good understanding of the project. It also gives the contractors a sense of ownership of the project, which in turns encourages the contractors to undertake waste minimisation during construction.

Therefore, for a waste minimisation-focused project such as this case study, the early involvements of the contractors should be welcome and encouraged.

7.10. Conclusion

This chapter has demonstrated the applicability of the framework to the evaluation of waste minimisation strategies for a range of C&D waste streams. The results obtained show that the building owner can get significant values from C&D waste minimisation. Further, all associated parties such as designer and contractors can also be beneficial economically from their involvement in the waste minimisation strategy. Finally, four waste minimisation strategies were analysed to make a recommendation on an optimal waste minimisation strategy for this case study.

The case study also explored roles and responsibilities of participants of the waste minimisation strategy to provide a good understanding of the contributing factors to a successful waste minimisation strategy.

The next chapter will discuss how this framework can be applied to a single waste stream (brick waste) in a different project setting (refurbishment).

**CHAPTER 8 – CASE STUDY TWO
ECONOMIC EVALUATION OF MINIMISING SINGLE C&D
WASTE STREAM**

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The economic evaluation framework described in Chapter 6 is intended to be flexible to various situations concerning C&D waste. Chapter 7 has demonstrated how the framework can be used to evaluate the economics of minimising multiple waste streams. This chapter will describe the application of this framework to the economic evaluation of minimising an individual waste stream: brick.

This chapter considers brick waste from both demolition and construction components of a project. However, unlike Chapter 7, this chapter investigates an office refurbishment project. The objective here is to demonstrate the flexibility and usefulness of this study's framework in various situations. Results obtained in this chapter will be thoroughly assessed and interpreted to provide a good understanding of the economic costs and benefits associated with minimising the brick waste stream.

In this case study, a real dataset with relative values is used and reported. In other words, the names and the magnitudes of the actual values have been altered for confidentiality reasons. This is appropriate for the purpose of demonstrating the application of the economic evaluation being reported in this thesis.

For the purpose in this case study, 'bricks' are red clay bricks, not concrete blocks and 'brick waste' is defined as broken bricks which cannot be used or reused whether in whole or in part.

8.1. Case Study Overview

The case study considered in this chapter is the refurbishment of a light commercial building in the Auckland Central area. This chapter will evaluate the economics of waste

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minimisation strategies associated with this project using the framework developed in Chapter 6.

8.1.1. Project Background

The building considered in this project is located in one of the main business districts in Auckland Central. It lies in a mixed-used area, including residential apartment buildings as well as business buildings. The total land area of the site (TL) is 691 m². However, the case study did not have the size of the building's footprint. For modelling purposes, it has been assumed that the building's footprint comprises 90% of the land area. This means the building footprint (F) is 622 m².

It has been estimated by the building owner (therein referred to as 'client') that the aggregated unit cost of project (AUC) is \$2,800. This unit cost was measured in dollar per square metre. This estimated unit cost includes the land value as well as the demolition and building costs.

Although this unit cost allows the building owner to evaluate the economic viability of the project, it was not useful for the economic modelling purposes due to its aggregated nature. Specifically, the inclusion of land value in the given unit cost can have a skewing effect because it does not reveal the true cost of the refurbishment work (i.e. demolition and construction work only). Therefore, for modelling purposes, it has been assumed that the value of the land comprises 40% of the specified unit cost. This is due to the fact that this land had been purchased by the client a long time ago, thus giving it a relatively lower cost than a comparable newly-purchased land block in the same area. This means the unit cost of land (UCL) is:

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$$\text{UCL} = \text{AUC} \times 40\% = \$2,800 \times 40\% = \$1,120 (\$/\text{m}^2)$$

Thus the unit cost of work (UCW) is the difference between the total unit cost (AUC) and the unit cost of land (UCL):

$$\text{UCW} = \text{AUC} - \text{UCL} = \$2,800 - \$1,120 = \$1,680 (\$/\text{m}^2)$$

Therefore, the total project budget - PB - (land excluded) is the product unit cost of work (UCW) and the building footprint (F):

$$\text{PB} = \text{F} \times \text{UCW} = 622 (\text{m}^2) \times \$1,680 (\$/\text{m}^2) = \$ 1,044,792.00 (\$)$$

Table 32 below summarises the above information:

Table 32: Refurbishment Project Summary

Item	Value	Unit
Total land area	691	m ²
Building footprint as percentage of total land area	90%	%
Building footprint of project	621.9	m ²
Estimated unit cost of project (incl. land and work)	\$ 2,800.00	\$/m ²
Land value as percentage of estimated project unit cost	40%	%
Estimated unit cost of land	\$ 1,120.00	\$/m ²
Estimated unit cost of work	\$ 1,680.00	\$/m ²
Estimated total project budget (excl. land)	\$1,044,792.00	\$

8.1.2. Breakdown of Project Budget

The building owner provided the breakdown of budget for each work package. This cost breakdown is for each work package is a percentage of the total project budget (PB). The budget breakdown is shown in Table 33. Based on this information, the cost of each work package can be estimated as shown in Table 34.

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Table 33: Project Budget Breakdown - Percentage (Supplied by Building Owner)

Work Package	Percentage of Project Budget
Design	11.94%
Demolition	1.82%
New works	80.54%
Planning	0.38%
Traffic	0.27%
Survey	0.72%
Council	1.82%
Legal	0.65%
Agency – Legal	3.76%

Table 34: Breakdown of Project Budget – Dollar Value (Calculated)

Work Package	Cost
Design	\$124,748.16
Demolition	\$19,015.21
New works	\$841,475.48
Planning	\$3,970.21
Traffic	\$2,820.94
Survey	\$7,522.50
Council	\$19,015.21
Legal	\$6,791.15
Agency – Legal	\$39,284.18

It was reported by the owner that their in-house personnel were used to manage the design and delivery of the entire project while external specialist contractors were used to undertake work in demolition, earthquake strengthening and construction.

It has been further reported in the case study that a significant recycled and reused bricks were used in this project. These recycled and reused bricks were salvaged, and came, from one of their demolition jobs that the client had undertaken in Auckland Central where the bricks were of the same era. This is in order that the building can retain its heritage characteristics. Not only did this practice save the owner money on materials but also help them build credentials in C&D waste minimisation. As a result, it

was reported by the client that they had got a significant ‘soft’ values such as marketability and exposure from this project.

8.2. Waste Generation Calculations

Since the data provided by the case study were aggregated, it is necessary to take extra steps to estimate the amount of waste generated during the refurbishment process (i.e. demolition and construction) for this case study. This research employs several sources of reference for this purpose. Table 35 summarises the information necessary for modelling and their respective reference sources.

Table 35: Key Modelling Assumptions (Brick Waste)

Category	Assumption Figure	Source
Bricks waste generation by weight (all waste)	600kg/m ²	Rawlinsons Construction Handbook, 2013
Brick wastage rate	5%	Construction Resources and Waste Platform, 2010
Brick waste arising by weight	1.889 tonnes per 100m ²	Construction Resources and Waste Platform, 2010

Assume the charge-out rate for a demolition crew is \$82 per square metre (Rawlinsons, 2011). The total area of demotion (A_d) is:

$$A_d = \$19,015.21 (\$) \div \$82 (\$/m^2) = 232 (m^2)$$

Based on the above information, it has been estimated that during the demolition process, the amount of waste generated (W_d) was:

$$\begin{aligned} W_d &= A_d \times 600 = 232 (m^2) \times 300 (kg/m^2) \\ &= 139,135.72 (kg) = 139.2 (tonnes) \end{aligned}$$

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As brick waste consists of 5% of all waste streams, it can be calculated below:

$$W_d = W_d \times 5\% = 139.2 \times 5\% = 6.96 \text{ (tonnes)}$$

Since the total area that requires brick work in this project is 253m², it can be estimated that the brick waste generated during construction is:

$$W_c = \frac{253 \times 1.889}{100} = 4.78 \text{ (tonnes)}$$

The total brick waste by weight in the project is therefore equal to:

$$W = W_d + W_c = 6.96 + 4.78 = 11.74 \text{ (tonnes).}$$

8.2.1. Design Costs

In this is a refurbishment project, the building owner indicated the total cost for design equalled 12% of the project budget. This was an aggregated figure without information on the breakdowns of individual design components. Therefore, for the purpose of this research, there is a need to disaggregate the design fee.

To achieve a successful disaggregation, this research relies on two documents: the 'NZIA 2007 1st Edition' and the 'Fee Guidelines for Consulting Engineering Services January 2004 – 1st Edition'.

It has been assumed in this research that this project has a relatively low level of complexity in design due to the fact that this is refurbishment project. In this research, a figure of 3% which was provided by the Client's project manager was used to calculate the design fee for architect.

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It has been reported by the client that the main area of work was the structural reinforcement of the building against potential earthquakes. As a result of this requirement, it was assumed that structural designs played an important role in design. This assumption was reflected in the design fees for structural and geotechnical engineering, where they equalled 4.2% and 2.4% of the project budget, respectively. Like above, these estimates were provided by the client’s project manager.

Table 36: Design Fee for Each Profession as Percentage of Total Project Budget

Actor	Percentage of design in total project budget
Architect	3.0%
Traffic Engineer	0.3%
Structural Engineer	4.2%
Geotechnical Engineer	2.4%
Mechanical Engineer	1.1%
Services Engineer	0.8%
Contractor	0.2%
Waste Management Contractor	0.1%
SUM	12.1%

Based on the information above, design fees for each designer in this project can be calculated accordingly (Table 37 below):

Table 37: Design Fee for Each Profession

Actor	Design fee
Architect	\$ 31,187.04
Traffic Engineer	\$ 2,820.94
Structural Engineer	\$ 43,661.86
Geotechnical Engineer	\$ 24,949.63
Mechanical Engineer	\$ 11,227.33
Services Engineer	\$ 8,732.37
Contractor	\$ 2,494.96
Waste Management Contractor	\$ 1,247.48
SUM	\$ 126,321.62

8.2.2. Design-out-waste Cost

As in Chapter 7, the design-out-waste component consists of a small percentage of the design fee. Further, the design-out-waste component can be incorporated into the design process for a relatively small cost. The interview with the client’s project manager suggests a figure of 2% of the project’s total design fee is sufficient – and this figure will be used in this case study to calculate cost of design-out-waste.

Table 38 shows the progressions of fees for design and design-out-waste component, respectively across seven strategies. The rate of increase is the same as those indicated in Chapter 6.

Table 38: Assumed Increases of Design Fees (Duplicate of Table 12)

From strategy to strategy	Rate of design fee increase
1 TO 2	20%
2 TO 3	10%
3 TO 4	10%
4 TO 5	10%
5 TO 6	15%
6 TO 7	30%

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Table 39: Cost of Design Increases

ACTOR	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Architect	\$ 31,187.04	\$ 37,424.45	\$ 41,166.89	\$ 45,283.58	\$ 49,811.94	\$ 57,283.73	\$ 74,468.85
Traffic Engineer	\$ 2,820.94	\$ 3,385.13	\$ 3,723.64	\$ 4,096.00	\$ 4,505.60	\$ 5,181.44	\$ 6,735.88
Structural Engineer	\$ 43,661.86	\$ 52,394.23	\$ 57,633.65	\$ 63,397.02	\$ 69,736.72	\$ 80,197.23	\$104,256.40
Geotechnical Engineer	\$ 24,949.63	\$ 29,939.56	\$ 32,933.52	\$ 36,226.87	\$ 39,849.55	\$ 45,826.99	\$ 59,575.08
Mechanical Engineer	\$ 11,227.33	\$ 13,472.80	\$ 14,820.08	\$ 16,302.09	\$ 17,932.30	\$ 20,622.14	\$ 26,808.79
HVAC Engineer	\$ 8,732.37	\$ 10,478.85	\$ 11,526.73	\$ 12,679.40	\$ 13,947.34	\$ 16,039.45	\$ 20,851.28
Contractor	\$ 2,494.96	\$ 2,993.96	\$ 3,293.35	\$ 3,622.69	\$ 3,984.96	\$ 4,582.70	\$ 5,957.51
Waste Management Contractor	\$ 1,247.48	\$ 1,496.98	\$ 1,646.68	\$ 1,811.34	\$ 1,992.48	\$ 2,291.35	\$ 2,978.75
SUM	\$126,321.62	\$151,585.95	\$166,744.54	\$183,418.99	\$201,760.89	\$232,025.03	\$301,632.54

Table 39 calculates the cost of design increases for each profession across seven levels of waste minimisation strategies. As waste minimisation requirements increase, the costs of design associated with corresponding waste minimisation strategies also increase.

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Table 40: Cost of Design-out-waste Increases

ACTOR	STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7
Architect	\$ 623.74	\$ 748.49	\$ 823.34	\$ 905.67	\$ 996.24	\$ 1,145.67	\$ 1,489.38
Traffic Engineer	\$ 56.42	\$ 67.70	\$ 74.47	\$ 81.92	\$ 90.11	\$ 103.63	\$ 134.72
Structural Engineer	\$ 873.24	\$ 1,047.88	\$ 1,152.67	\$ 1,267.94	\$ 1,394.73	\$ 1,603.94	\$ 2,085.13
Geotechnical Engineer	\$ 498.99	\$ 598.79	\$ 658.67	\$ 724.54	\$ 796.99	\$ 916.54	\$ 1,191.50
Mechanical Engineer	\$ 224.55	\$ 269.46	\$ 296.40	\$ 326.04	\$ 358.65	\$ 412.44	\$ 536.18
HVAC Engineer	\$ 174.65	\$ 209.58	\$ 230.53	\$ 253.59	\$ 278.95	\$ 320.79	\$ 417.03
Contractor	\$ 49.90	\$ 59.88	\$ 65.87	\$ 72.45	\$ 79.70	\$ 91.65	\$ 119.15
Waste Management Contractor	\$ 24.95	\$ 29.94	\$ 32.93	\$ 36.23	\$ 39.85	\$ 45.83	\$ 59.58
SUM	\$ 2,526.43	\$ 3,031.72	\$ 3,334.89	\$ 3,668.38	\$ 4,035.22	\$ 4,640.50	\$ 6,032.65

Table 40 calculates the cost of design-out-waste increases for each profession across seven levels of waste minimisation strategies.

As waste minimisation requirements increase, the costs associated with design-out-waste also increase.

8.2.3. Unit Cost of Brick

For the mathematical modelling purposes, it has been assumed that the average market price (P_{am}) of each brick is NZD\$1.20 (New Zealand Brick Distributor, 2016). Given that a standard-sized brick weighs 2.5kg (s), a tonne of brick (t) will hence consist of 400 bricks.

$$t = \frac{1000}{2.5} = 400 \text{ (bricks)}$$

This means a tonne of brick will cost (U_{brick}):

$$U_{brick} = P_{am} \times t = \$1.2 \times 400 = \$480$$

On the other hand, there is limited market for recycled or salvage bricks in New Zealand, thus making it difficult to obtain market price for such second-hand materials. Therefore, an assumption of \$50 per tonne has been made for recycled bricks. This assumption was based on publicly available information from New Zealand's largest auction and trading website: www.trademe.co.nz. Although this is not a wholesale website, the fact that it is New Zealand's largest trading platform means the information on it is reliable and applicable to the New Zealand market.

8.3. Unit Cost Calculations

As in Chapter 7, this chapter uses the same sources of information for calculations of unit costs.

8.3.1. Base Rates for Calculations

Information regarding charge-out rates for machinery and haulage charges are the same as that in Table 20 and Table 21 in Chapter 7.

Unit costs calculated in this section include unit cost of waste collection, unit cost of sorting waste, unit cost of recycling waste, unit cost of reusing waste and unit cost of energy used.

8.3.2. Unit Cost of Collecting Waste

As in Section 7.4.2, using Google Maps, this research calculated that the average distance travel within Auckland to landfills (d) is 60.3 kilometres. Given the haulage rate (hr) is \$5 per kilometre and a loading factor (lf) of 1.5, the cost of haulage per trip (H) is:

$$H = d \times hr \times lf = 60.3 \text{ (km)} \times 5 \text{ (\$/km)} \times 1.5 = \$452.25 \text{ (\$)}$$

Hence the unit cost of waste collection is (U_c) is a division of haulage cost per trip (H) by the truck capacity (c), this gives:

$$U_c = \frac{H}{c} = \frac{\$452.25}{12 \text{ (tonnes)}} = \$38.52 \text{ (\$/tonne)}$$

8.3.3. Unit Cost of Sorting Waste

The number of machines (Ma) needed to process 11.74 tonnes of C&D waste (w) in this project is:

$$Ma = \frac{c}{w} = \frac{12 \text{ (tonnes)}}{11.74 \text{ (tonnes)}} = 1 \text{ (machine)}$$

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Although the actual amount of machinery may be different to the number of machine(s) calculated above, for modelling purposes, it is believed this is sufficient.

According to Rawlinsons, the average charge-out rate (Cr) for machinery with associated labour (i.e. including driver/operator) is \$120 per hour (Rawlinsons, 2011).

Hence, the total charge-out (TCr) rate for 1 machine is:

$$TCr = Ma \times Cr = 1 \times \$120 = \$120 (\$/hour)$$

Suppose it takes half an hour (Ts) to sort one 12-tonne capacity skip bin full of waste, the total time (T) taken to sort out all 11.74 tonnes of waste is:

$$T = \frac{w \times Ts}{c} = \frac{11.74 \text{ (tonnes)} \times 1 \text{ (hours)}}{12 \text{ (tonnes)}} = 1 \text{ (hours)}$$

The client's project manager reported that the waste sorting rate (Rs) is 90%. Based on this information, a total of waste sorted (Ws) is:

$$Ws = w \times 90\% = 11.74 \times 90\% = 10.57 \text{ (tonnes)}$$

Therefore, the unit cost of waste sorting is:

$$Us = \frac{TCr \times T}{Ws} = \frac{120 \left(\frac{\$}{hour} \right) \times 1 \text{ (hours)}}{10.56 \text{ (tonnes)}} = \$11.36 (\$/tonne)$$

8.3.4. Unit Cost of Recycling and Reusing Waste

It must be noted that although a C&D waste sorting rate in this project is around 90%, not all sorted brick waste was reusable or recyclable and thus residual brick waste was present. It was reported by the client that in this project 70% of all waste generated was recycled. For modelling purposes, a brick recycling rate (RR) of 70% is used.

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This means the total waste recycled (SM) is:

$$SM = w \times RR = 11.74 \text{ (tonnes)} \times 70\% = 7.4 \text{ (tonnes)}$$

Assuming it takes 1 hour to process and recycle C&D waste, the total hours (Tr) needed to process and recycle waste is:

$$Tr = SM \times 1 = 7.4 \text{ (tonnes)} \times 1 \text{ (hour/tonne)} = 7.5 \text{ (hours)}$$

Therefore, the unit cost of recycling is:

$$U_{rc} = \frac{Tr \times Cr}{SM} = \frac{7.5 \text{ (hours)} \times 120 \text{ (\$/hour)}}{7.5 \text{ (tonnes)}} = \$120 \text{ (\$/tonne)}$$

Calculation for reusing waste is similar to that of recycling waste. As a result, the unit cost of reusing waste is $U_{rw} = \$120 \text{ (\$/tonne)}$

8.3.5. Unit Cost of Energy

The total trips (T_{trip}) required to cart away the project's C&D waste is:

$$T_{trip} = \frac{w}{c} = \frac{11.74 \text{ (tonnes)}}{12 \text{ (tonnes/trucks)}} = 1 \text{ (trucks or trips)}$$

For modelling purpose, each of the above 1 trucks or trips can be treated as a unit of machinery. Combine with the machinery required for processing waste, the total units of machinery required for the entire project is:

$$T_{machine} = T_{trip} + Ma = 1 + 1 = 2 \text{ (machines)}$$

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Based on Rawlinsons' information, the average fuel capacity (F) of a large machine/truck is 450 litres and the cost of diesel fuel (cf) is \$3 per litre (Rawlinsons, 2011). This means the unit cost of energy used by all machinery is:

$$U_{en} = \frac{T_{machine} \times F \times cf}{w} = \frac{2 \text{ (machines)} \times 450 \text{ (L)} \times 3 \left(\frac{\$}{L}\right)}{11.74 \text{ (tonnes)}}$$

$$U_{en} = \$229.983 \text{ (\$/tonne)}$$

As in Chapter 7, it has been assumed in this study that the energy and processing costs will be increased by 25% and 50% for Levels 6 and Level 7 strategies, respectively, compared to the baseline strategy (Level 1). This is in order to reflect the significant increases in investments that must be spent to achieve zero waste.

8.4. Benefit Assumptions

8.4.1. Direct Benefits

The client reported that by using their in-house expertise and resources, the building owner could save significant costs for professional services. It has been further reported by the building owner that this redevelopment project was economically sound for a number of key reasons.

First, the redevelopment provided their business with a modern and state-of-the-art working environment in a highly sought-after Auckland fringe location. It has been reported by that the redevelopment has expanded the available floor space by 50% compared to their old office. The owner has also reported on the significant improvement in quality, resulting in improvement in productivity and comfort levels by

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their staffs. From a real estate perspective, this project has added significant commercial values to the building owner's organisation.

The second benefit to the owner is by undertaking this project using in-house expertise, they had an opportunity to showcase their capability to deliver a quality project on-time within budget. In turns, this has helped their company enhance their reputational profile significantly.

Finally, by moving to the newly-developed office, the owner could lease out their old office. This means the development has helped them generate additional cash flows. It has been reported by the owner that over the long term, they could also have an opportunity to achieve highly competitive rentals should they wish to vacate the current premises in the future.

The owner has acknowledged that in all direct benefits that have realised, C&D waste minimisation, including that for brick waste, played an important role and they see values in undertaking waste minimisation practices in this project.

8.4.2. Valuing Client's Benefits

The above information shows there were high levels of benefit that can be derived from this project by the building owner. However, they did not quantify values for such benefits. Rather, the client's project manager provided a high-level monetised estimate of around \$10,000 for all intangible benefits the client realised 6 months after moving into the new premises. For the modelling purposes, this research uses a lower value of \$7,000 to quantify intangible benefits to cater for uncertainties in the client's estimates.

Although this \$7,000 figure is conservative, it is sufficient for the economic evaluation of minimisation strategies for brick waste.

8.5. Economic Evaluation Results

As in Chapter 7, Microsoft Excel™ is chosen as the modelling tool for this chapter.

In this case study, seven waste minimisation strategies were considered. They were Level 1 (baseline analysis - disposing of waste to landfill); Level 2 (minimising waste by 5%-10%); Level 3 (minimising waste by 11%-30%); Level 4 (minimising waste by 31%-50%); Level 5 (minimising waste by 51%-70%); Level 6 (minimising waste by 71%-95%) and Level 7 (zero waste).

Using the formulations established in Chapter 6, result for each strategy is shown in Table 41 and Figure 7 below. Detailed discussions on Table 41 and Figure 7 are offered in the following sections.

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BENEFIT COMPONENT	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7
Intangible benefits	\$ 7,000.00	\$ 7,000	\$ 7,000	\$ 7,000	\$ 7,000	\$ 7,000	\$ 7,000
Cost saving from reusing	\$ -	\$ 126	\$ 277	\$ 783	\$ 1,288	\$ 1,793	\$ 2,525
Cost saving from recycling	\$ -	\$ 126	\$ 277	\$ 782	\$ 1,288	\$ 1,793	\$ 2,525
Cost saving from dumping material	\$ -	\$ 88	\$ 193	\$ 546	\$ 898	\$ 1,251	\$ 1,762
Revenue from selling of construction waste materials	\$ -	\$ 29	\$ 64	\$ 182	\$ 299	\$ 417	\$ 587
Total cost saving	\$ 7,000	\$ 7,281	\$ 7,620	\$ 8,748	\$ 9,875	\$11,003	\$12,639
COST COMPONENT	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7
Cost of design-out-waste	\$ 2,526	\$ 3,031	\$ 3,334	\$ 3,668	\$ 4,035	\$ 4,640	\$ 6,032
Cost of Waste Strategy	\$1,462	\$1,462	\$1,462	\$1,462	\$1,462	\$1,462	\$1,462
Expected cost of waste collection	\$ 452	\$ 429	\$ 402	\$ 312	\$ 221	\$ 131	\$ -
cost of waste to landfill	\$ 1,762	\$ 1,674	\$ 1,568	\$ 1,216	\$ 863	\$ 511	\$ -
cost of recycling waste	\$ -	\$ 17	\$ 38	\$ 109	\$ 179	\$ 312	\$ 528
cost of reusing waste	\$ -	\$ 17	\$ 38	\$ 109	\$ 179	\$ 312	\$ 528
cost of energy used in reusing	\$ -	\$ 67	\$ 148	\$ 418	\$ 688	\$ 1,199	\$ 2,026
cost of energy used in recycling	\$ -	\$ 67	\$ 148	\$ 418	\$ 689	\$ 1,199	\$ 2,026
material waste cost	\$ 5,639	\$ 5,357	\$ 5,018	\$ 3,890	\$ 2,763	\$ 1,635	\$ -
Total Cost of Waste	\$11,842	\$12,193	\$12,310	\$12,025	\$11,772	\$12,603	\$14,631
Benefit-Cost Analysis	59%	60%	62%	73%	84%	87%	86%

Table 41: Modelling Result - Case Study Two

COST SAVING VERSUS COST OF WASTE STRATEGIES

- LEVEL 7
- LEVEL 6
- LEVEL 5
- LEVEL 4
- LEVEL 3
- LEVEL 2
- LEVEL 1

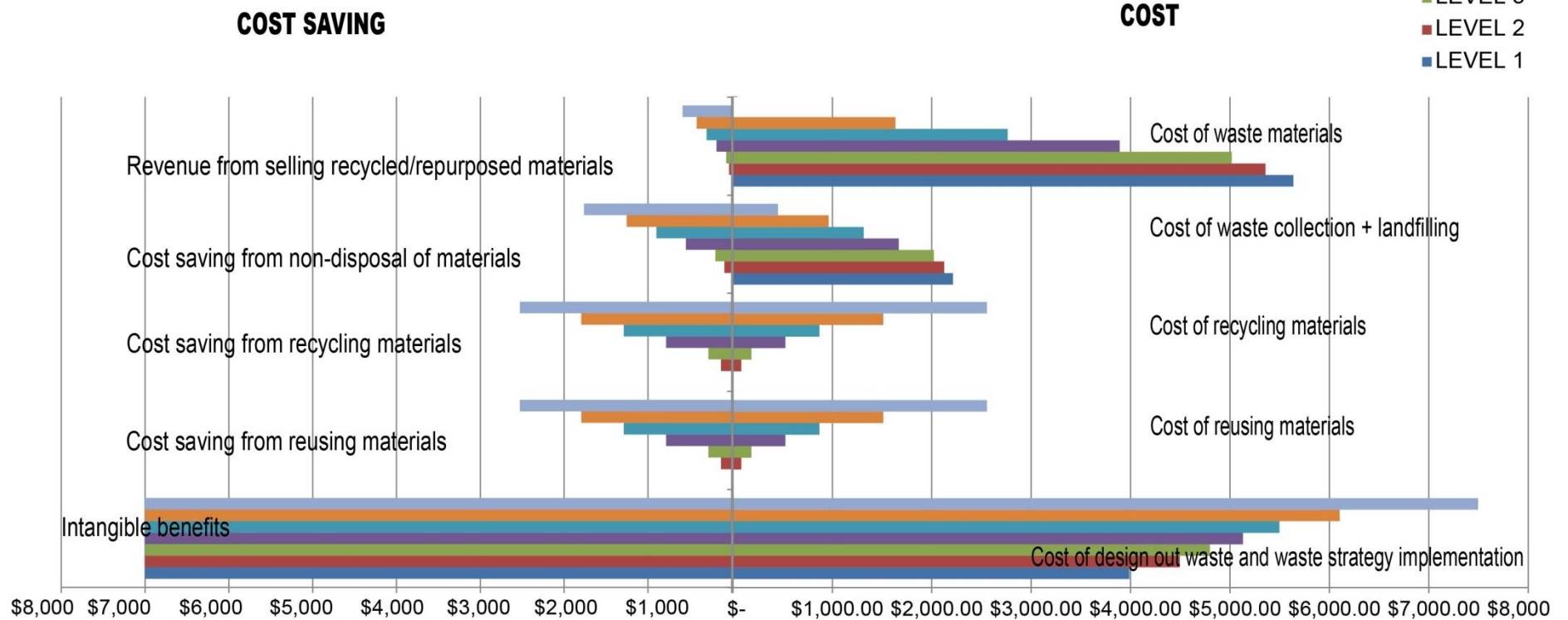


Figure 7: Tornado Chart of Benefits and Costs - Case Study Two

8.6. Analysis

This section provides detail analyses of the results obtained from the Section 8.5 above. Like in Chapter 7, this chapter considers three areas in its analysis:

- a) Cost of waste versus savings from waste minimisation
- b) Cost effectiveness of waste minimisation via design-out-waste; and
- c) Economic efficiencies of waste minimisation strategies

8.6.1. Basis of Comparison

In this research, efforts have been made by the researcher to ensure consistency is maintained. For comparison purposes, necessary moderations in calculations were made to make sure costs were compared to corresponding cost savings appropriately. In this case study, moderations were undertaken in a similar manner to those in the case study reported in Chapter 7.

Cost savings/benefit components and their corresponding cost components are similar to the basis of comparison conversion in Table 25 in Chapter 7.

Table 42 below presents the modelling results after conversion. As shown in Table 42, costs of waste fluctuate; while cost savings increase progressively as rigorous waste minimisation strategies are implemented. This results in an increasing benefit-cost ratio across all seven strategies considered (Levels 1 – 7).

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Table 42: Modelling Results of Case Study Two

LEVEL	1	2	3	4	5	6	7
Benefit Component							
Intangible benefits	7,000	\$7,000	\$7,000	\$7,000	\$7,000	\$7,000	\$7,000
Cost saving from reusing materials	\$ -	\$ 126	\$ 278	\$ 783	\$1,288	\$1,793	\$2,525
Cost saving from recycling materials	\$ -	\$ 126	\$ 278	\$ 7823	\$1,288	\$1,793	\$2,525
Cost saving from non-disposal of materials	\$ -	\$ 88	\$ 194	\$ 546	\$ 898	\$1,251	\$1,762
Revenue from selling recycled materials	\$ -	\$ 29	\$ 64	\$ 182	\$ 299	\$ 417	\$ 587
Total Cost Savings/Benefits	\$7,000	\$7,282	\$7,620	\$ 8,748	\$ 9,876	\$11,003	\$12,639
Cost Component							
Cost of design out waste + waste strategy	3,989	\$4,494.	\$4,797	\$5,131	\$5,498	\$6,103	\$7,495
Cost of reusing materials	\$ -	\$ 85	\$ 187	\$ 528	\$ 868	\$1,511	\$2,555
Cost of recycling materials	\$ -	\$ 85	\$ 187	\$ 528	\$ 868	\$1,511	\$,555
Cost of waste collection + landfilling	\$2,214	\$2,126	\$2,021	\$1,668	\$1,316	\$ 963	\$ 452
Cost of waste materials	\$5,639	\$5,357	\$5,018	\$3,891	\$2,763	\$1,635	\$ -
Total Cost of Waste	\$11,842	\$12,148	\$12,211	\$11,746	\$11,314	\$11,725	\$13,057
BENEFIT-COST RATIO	59%	60%	62%	74%	87%	94%	97%

8.6.2. Costs versus Cost Savings

The cost saving components of each waste minimisation strategy was charted against their respective cost components as in Figure 5.

8.6.2.1. Analysis of Base Waste Strategy (Level 1 - 'Do-Nothing')

As can be seen in Figure 7, Level 1 waste strategy has the highest cost of waste among the seven waste strategies considered. At the same time, its cost of waste strategy remains the lowest. This is logical because as a base strategy, there is no need for waste minimisation strategy at this level. Rather, all brick waste generated would simply be disposed of into landfills.

As all brick waste would end up in landfill, the base strategy does not incur any recycling and repurposing costs to the client. Perhaps this is the only upside in this strategy.

However, this strategy is not a cost effective strategy for the client due to its lack of cost saving offered. When this strategy is chosen, the client has in effect buried any potential cost savings that can be derived such 'waste'. Further, as waste ends up in landfills, no processed materials can be on-sold to the secondary markets to offset the costs of purchasing the original materials.

Further, this strategy can be potentially damaging to the environment due to the lack of treatments of waste before disposal. Due to this lack of care for environment, this strategy has a potential to contribute to the continuing, and significantly, high percentage of C&D waste being present in all landfill waste streams.

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Therefore, from an investment perspective this strategy may not be economically sound for the client. With a benefit - cost ratio of 59%, this is the least efficient strategy. Thus from an economic perspective it is likely that the client would explore other alternatives.

8.6.2.2. Analysis of Level 2 and Level 3 Waste Minimisation Strategies

Waste minimisation strategies Level 2 and Level 3 show similar results to that of the base waste strategy (Level 1). Despite more investments in waste minimisation by the client, the waste reduction rates of 5% and 11% do not seem to have made any major impacts in terms of economic efficiency compared to that of Level 1. In fact the economic efficiencies of Level 2 and Level 3 strategies are only 1% and 2% better than the economic efficiency of Level 1 strategy (at 60% and 62%), respectively. This minor improvement again may not justify the investments by the client. Thus these waste minimisation strategies will also likely be ignored by the client.

8.6.2.3. Analysis of Level 4 Waste Minimisation Strategy

At this level, despite 31% of brick waste can be diverted, there are still significant costs associated with waste material (cost of waste materials) and disposal (cost of collection and landfilling). Although there are some associated cost-savings are being realised, the fact that these costs are high shows this strategy does not adequately address the waste issue.

BCR of this strategy is reasonably high at 74%. This shows the client start to receive the benefits from their investments on waste minimisation. This realisation can encourage the client to undertake more rigorous waste minimisation strategies.

8.6.2.4. Analysis of Levels 5, 6 and 7 Waste Minimisation Strategies

The economic efficiencies of these three levels are similar with BCRs of 87%, 94% and 97%, respectively. This means the investments that the client makes into waste minimisation at these levels can deliver values, but do not deliver the total economic efficiency that the client is looking for.

Moreover, the actual profile of each strategy is totally different. At Level 5, the cost of waste materials is still relatively high compared to the revenue that can be realised from reselling recycled materials. However, at Level 6 and Level 7, the cost and revenue in this component more or less equal. This is because unlike at Level 5, at Level 6, a significant waste has been reduced, thus reducing the cost of waste; while at Level 7, there is no waste generated so all bricks can be recycled and/or resold.

However, the costs of reuse and recycling are much higher in Level 6 and Level 7 strategies than they are in Level 5 strategy. As more materials being saved, more resources and money must be spent to recycle and repurpose the bricks in order to resell them in the secondary market. Further, the energy needed at these levels increase by 25% and 50% respectively compared to that in lower levels. This makes the costs of recycling and reusing at Levels 6 and 7 more expensive than their contemporaries.

8.6.2.5. Implications of Zero Waste

It can be observed from Figure 7 that the design cost for the zero waste strategy is highest among all strategies considered. This behaviour is similar to that in Chapter 7. Perhaps the high design cost here is due to two elements: the time and effort required by designers to ensure no waste is generated; and the high cost of compliance

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associated with the rigorous waste minimisation practices required by the zero waste strategy.

In the first element, to achieve zero waste, it is anticipated that the design team (including architects, engineers and contractors) must spend time and effort to design systems that does not generate waste during construction. It is no doubt that such a system, if it exists, would be highly complex. This time and effort spent on design also means that the cost associated with design will likely increase.

Once a waste minimisation system has been designed, it must be implemented in order to achieve the 'zero waste' objective. It is contended that due to construction's fragmented nature, the implementation of such a system would be highly complicated. Therefore, there will be a need for a rigorous implementation plan as well as associated compliance strategy. This requirement means that the cost associated with a waste minimisation strategy will likely increase as well.

However, despite its high investment cost, the zero waste strategy does not deliver a significantly high return for the client in this case study. This is shown by the fact that the BCR of Level 7 strategy is slightly higher than that of Level 6 strategy (97% compared to 94%, respectively). This means that in this instance, it may be worth the client's effort to look at another waste minimisation alternative to the zero waste. This is because the client can avoid the high investment cost associated with the zero waste strategy; and at the same time the client can achieve a similar or better return on his investment. The comparison of economic efficiencies between waste minimisation strategies will be discussed in detail in Section 8.7.

8.6.3. Analysis of Design-Out-Waste

Design-out-waste cost comprises a small portion (2%) of the total design cost of this project. However, the rate of design cost increases between different waste minimisation levels are as per Table 40. Such increases are significant nonetheless; and they could have significant implications on design-out-waste costs.

As the design cost increases, the cost of design-out-waste component also increases proportionally. This is a response to the increased complexity in waste minimisation requirements. As more waste is being minimised, the designers must find more innovative ways to help meet this goal. This means the designers must collaborate with other parties, including contractors and material manufacturers, to research and incorporate durable materials or materials that can be reused / recycled after their useful lives in the design. The increased cost is a reflection of the increased efforts and time spent on researching, understanding and designing systems that can offer minimal wastages.

8.6.3.1. *Design Participants' Learning*

The design-out-waste is a complex and time-consuming process involving participations of different parties, all of whom must get paid. And their payments should be proportional to the increased complexity. Subsequently, the cost breakdown for each actor in design-out-waste (and design – i.e. the sum) can be calculated.

Tables 43 – 45 demonstrate that aside from traditional designers such as architects and engineers, contractors also make money for their involvement in the design stage. From an investment perspective, it is a promising idea and good practice to get the

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contractors involved early in the design process for two reasons. First, the early involvement of the contractors in the design stage can help improve the overall constructability of the project with their practical inputs. This means significant process waste can be reduced due to prompt communication between the designers and the contractors.

Second, by being involved in the design stage, contractor will likely take ownership of their work. This means the contractor will likely take proactive actions to reduce and minimise wastages during construction. At the same time, the contractor will have incentives to require sub-contractors to take actions to reduce and minimise waste.

As argued in Chapter 7, the fragmented nature of the construction industry means that a majority of actual construction will be delegated or subcontracted. This means the subcontractor, as opposed to the contractors, will be responsible for ensuring the waste minimisation targets are met. To achieve this goal, the subcontractor must ensure they have appropriately trained personnel to carry out the work during construction, at their costs. From the perspective of the main contractors, their involvement in a waste minimisation-focused project presents significant benefits from this project with minimal to no downsides. Benefits that the contractors can get are both tangible and intangible. Tangible benefits come from earnings from design, free training in waste minimisation while intangible benefits come from marketing exposures and improved reputation. This means the contractor can get more benefits from a waste minimisation project compared to a non-waste-focused project of a similar construction price. From an economic perspective, the contractor would likely prefer being involved in, and committed to, a waste minimisation-focused building project.

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Table 43: Design Cost and Design-Out-Waste Cost for Waste Minimisation Strategies

WASTE MINIMISATION STRATEGY	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7
DESIGN COST	\$ 126,321	\$ 151,586	\$ 166,744	\$ 183,419	\$ 201,761	\$ 232,025	\$ 301,632
DESIGN-OUT-WASTE COST	\$ 2,526	\$ 3,031	\$ 3,335	\$ 3,668	\$ 4,035	\$ 4,640	\$ 6,032

Table 44: Increases in Design-Out-Waste Cost (Percentage)

ACTOR	PERCENTAGE OF DESIGN IN TOTAL REFURBISHMENT PROJECT COST						
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7
Architect	3.0%	3.6%	3.9%	4.3%	4.8%	5.5%	7.1%
Traffic Engineer	0.3%	0.3%	0.4%	0.4%	0.4%	0.5%	0.6%
Structural Engineer	4.2%	5.0%	5.5%	6.1%	6.7%	7.7%	10.0%
Geotechnical Engineer	2.4%	2.9%	3.2%	3.5%	3.8%	4.4%	5.7%
Mechanical Engineer	1.1%	1.3%	1.4%	1.6%	1.7%	2.0%	2.6%
HVAC Engineer	0.8%	1.0%	1.1%	1.2%	1.3%	1.5%	2.0%
Contractor	0.2%	0.3%	0.3%	0.3%	0.4%	0.4%	0.6%
Waste Management Contractor	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.3%
SUM	12.1%	14.5%	16.0%	17.6%	19.3%	22.2%	28.9%

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Table 45: Increases in Design-Out-Waste Cost (Dollar Value)

ACTOR	COST						
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7
Architect	\$ 31,187.04	\$ 37,424.45	\$ 41,166.89	\$ 45,283.58	\$ 49,811.94	\$ 57,283.73	\$ 74,468.85
Traffic Engineer	\$ 2,820.94	\$ 3,385.13	\$ 3,723.64	\$ 4,096.00	\$ 4,505.60	\$ 5,181.44	\$ 6,735.88
Structural Engineer	\$ 43,661.86	\$ 52,394.23	\$ 57,633.65	\$ 63,397.02	\$ 69,736.72	\$ 80,197.23	\$ 104,256.40
Geotechnical Engineer	\$ 24,949.63	\$ 29,939.56	\$ 32,933.52	\$ 36,226.87	\$ 39,849.55	\$ 45,826.99	\$ 59,575.08
Mechanical Engineer	\$ 11,227.33	\$ 13,472.80	\$ 14,820.08	\$ 16,302.09	\$ 17,932.30	\$ 20,622.14	\$ 26,808.79
HVAC Engineer	\$ 8,732.37	\$ 10,478.85	\$ 11,526.73	\$ 12,679.40	\$ 13,947.34	\$ 16,039.45	\$ 20,851.28
Contractor	\$ 2,494.96	\$ 2,993.96	\$ 3,293.35	\$ 3,622.69	\$ 3,984.96	\$ 4,582.70	\$ 5,957.51
Waste Management Contractor	\$ 1,247.48	\$ 1,496.98	\$ 1,646.68	\$ 1,811.34	\$ 1,992.48	\$ 2,291.35	\$ 2,978.75
SUM	\$ 126,321.62	\$ 151,585.95	\$ 166,744.54	\$ 183,418.99	\$ 201,760.89	\$ 232,025.03	\$ 301,632.54

8.6.3.2. Cost Implications to the Building Owner

From the building owner’s perspective, the investment in design can offer significant potential pay-offs. Having a good design with thorough considerations for waste can result in fewer materials are being wasted in a project. This allows to them to receive significant cost savings. As shown in Figure 7, the cost savings offered to the client in both Level 6 and Level 7 strategies outweigh the costs associated to the same components. These are tangible and measurable benefits. However, the owner can also get significant ‘soft’ benefits from the project. Some ‘soft’ benefits include, but not limited to, improved reputation, improved productivity as a result of comfortable working environment and from marketing in the news/media. Although it can be difficult to quantify these ‘soft’ or intangible benefits, they exist and are of values to the client.

As shown in tables 43 – 45 above, the design-out-waste cost and design cost increase proportionally depending on the types of waste minimisation strategy. However, given the significant benefits that the owner could realise from this project, increases in costs did not deter the client from undertaking a waste minimisation strategy.

8.7. Benefit-Cost Analysis

In this section, BCRs of all seven waste minimisation strategies in this project are extracted from Tables 41 and 42 and presented in Table 46 and Figure 8.

Table 46: BCR of C&D Waste Minimisation Strategies - Case Study Two

LEVEL	1	2	3	4	5	6	7
Total Cost Saving	\$7,000	\$7,282	\$7,620	\$ 8,748	\$ 9,876	\$11,003	\$12,639
Total Cost of Waste	\$11,842	\$12,148	\$12,211	\$11,746	\$11,314	\$11,725	\$13,057
BCR	59%	60%	62%	74%	87%	94%	97%

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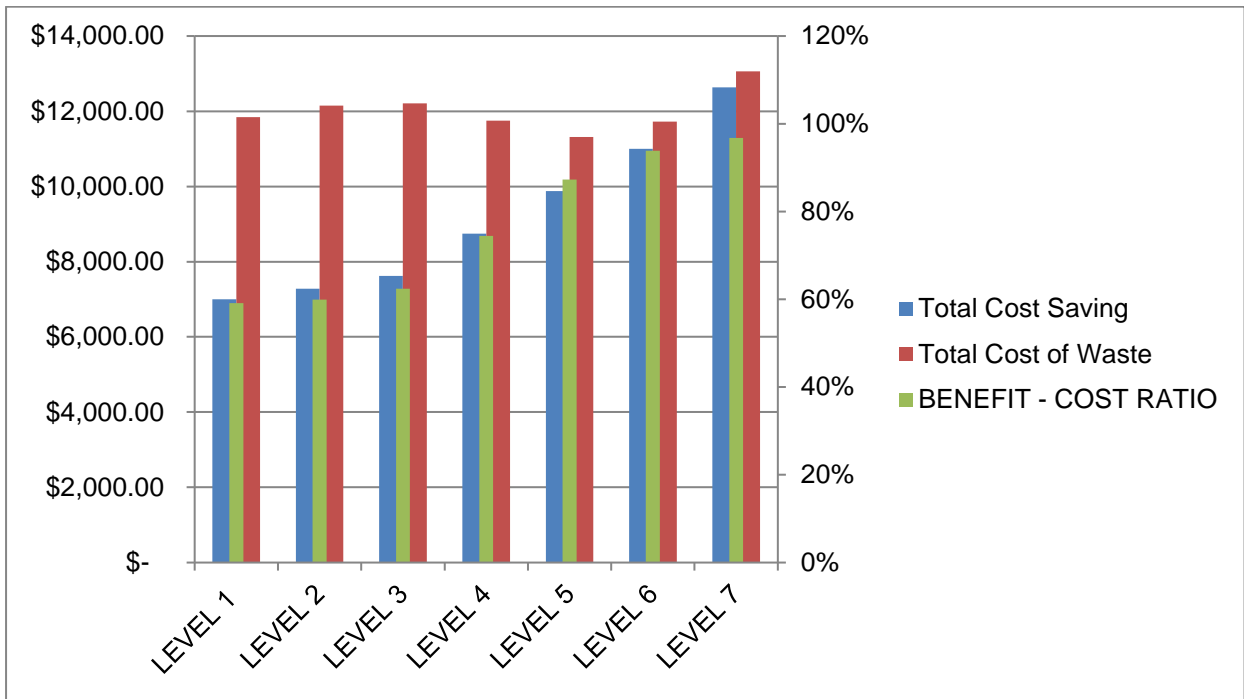


Figure 8: Representation of Results - Case Study Two

As can be seen in Figure 8, there is an upward trend in cost savings across seven strategies. This shows the benefits to the building owner increase as waste minimisation strategies get more rigorous.

However, there are fluctuations in the costs associated with these strategies. This shows there is a degree of economic uncertainty around the increased energy costs when implementing intensive waste minimisation strategies (Level 6 and Level 7).

In many countries, brick waste is processed to make aggregates for road works. This creates a secondary market for brick waste. Similarly, many countries use bricks as a key building material and old or recycled bricks can be traded to be used in buildings. As such, there is a secondary market for recycled and old bricks. However in New Zealand there are no such similar markets as road aggregates are often mined while bricks are not a key building material here. This lack of secondary market is a problem

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for many types of recycled materials, not just bricks. And as a result, a significant economic uncertainty is created around the opportunities around, and the resale values of, recycled materials.

Despite this uncertainty, there is an upward trend in the BCRs across all seven strategies considered.

8.7.1. BCR of Level 1

Of all strategies under consideration, waste strategy Level 1 offers the lowest BCR of 59%. This strategy has the lowest benefits offered to client. From an investment perspective, this strategy is unlikely to be implemented, given its low level of economic efficiency.

8.7.2. BCR of Level 2 and Level 3

The BCRs of Level 2 and Level 3 are similar to that of Level 1 (at 60% and 62% respectively). From an investment perspective, these strategies are also unlikely to be implemented, given the low levels of return on investment.

8.7.3. BCR of Level 4

This strategy offers the owner a relatively high degree of economic efficiency, with BCR equalling 74%. This is a mid-tier strategy, with a high cost of waste and a moderate return level (benefits). This strategy may be worth considering, given its high economic efficiency level. The only downside of this strategy is its low level of waste reduction (31%). Therefore, it is worth exploring other alternatives before settling for this option.

8.7.4. BCR of Level 5

Under this strategy, at least 51% of C&D waste must be reduced and diverted from landfill. This is a significant waste minimisation requirement and thus has required a significant level of investments in design and implementation. Due to a relatively high level of investment it has received, the baseline waste minimisation strategy has achieved a high degree of economic efficiency. The BCR of this strategy equals 87%. Overall, this strategy has a relatively low energy cost compared to Level 6 and Level 7 strategies. However, the costs of waste disposal and material waste remain higher than those of Level 6 and Level 7 strategies. Nevertheless, this strategy is worth considering, given its high economic efficiency level and relatively high waste reduction rate.

8.7.5. BCR of Level 6 and Level 7

Both Level 6 and Level 7 waste minimisation strategies can offer the client similar economic efficiency rates (94% and 97%, respectively). It can be observed that BCRs of Level 6 and Level 7 strategies are similar and coupled with the high waste reduction rates, both Level 6 and Level 7 can provide the building owner value for money. It is thus worth comparing the Level 6 waste minimisation strategy and the Level 7 zero waste strategy. This comparison is useful because it can help identify an optimal waste minimisation strategy for this case.

Overall, Level 6 has a much lower cost in three main cost categories than the zero waste strategy. These categories are design-out-waste, recycling and reusing waste. However, since Level 6 strategy can only reduce 71% of C&D waste, there is still a significant wastage present in this strategy. This in turns means that the costs

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associated with waste disposal and material waste in Level 6 strategy is much higher than those in the zero waste strategy.

In a zero waste strategy there is no cost of disposal, as all 'waste' is now 'resources' for industrial processing; thus eliminating the need to dispose of waste to landfills. At the same time, the building owner also achieves significant increases in cost savings due to this elimination. The net effect of decreased costs and improved benefits is the BCR under this strategy has increased slightly (97% compared to 94% in Level 6 strategy). This minor increase in BCR is due to the aggressive steps taken in minimising waste streams.

However, as argued in Chapter 7, it may not be possible to achieve zero waste, as it is an idealised concept. As such, in reality the Level 7 waste minimisation is impractical despite its high economic efficiency yielding. On the other hand, Level 6 waste minimisation is achievable, and has been achieved in this actual case study. As both strategies give the client (i.e. the building owner) similar economic efficiencies that are close to 100%, and Level 6 is more achievable than Level 7, it is contended in this research that the Level 6 waste minimisation is the optimal strategy for this case study.

Therefore, it can be argued that it is worth undertaking a waste minimisation in this case; but the waste minimisation rate must be at least 71% to ensure an appropriate level of returns on investment.

8.8. Findings

8.8.1. Waste Strategy Level 1 – Landfilling

From the analysis sections, there is little value to the client in disposing of C&D waste to landfill. By sending brick waste to landfill, the owner gets little economic benefit. The only benefit the client could receive in this strategy is the savings from onsite labour costs from waste segregation. However, the owner was still liable for a cost for disposing of such waste, meaning they would end up paying twice for the same material. Initially the client must pay for the new and virgin materials for the construction of the building. Then once some bricks are demoted to 'waste' during the construction process, the client must also pay a fee to dispose of this waste.

Further, as shown in the framework, a high landfill charge of \$150 per tonne makes the practice of disposing of waste an expensive option. Because of this the client should start to look for approaches to reduce their brick waste output.

8.8.2. Levels 6 and 7 Waste Minimisation Strategies

Unlike the 'landfill' option, the building owner can get significant economic advantages from higher-level waste minimisation strategies such as those in Level 6 and Level 7. These advantages include opportunities to save on materials (as limited wastages occur or end up in landfills under these strategies); opportunities to save on transportation costs (as materials can be delivered on demand, and minimal dumping trucks required under these strategies); and opportunity to on-sell the excess materials to secondary markets.

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In addition, under waste minimisation strategies, the client has an opportunity to engage closely with other stakeholders such as architects, engineers and contractors to manage and minimise waste. These collaborations can be explicitly expressed via penalty/incentive schemes to encourage the stakeholders to uptake waste management practices throughout the project. It has been argued by Tam & Tam (2008) that an introduction of a penalty/incentive scheme can enhance the chance of achieving the project's waste minimisation goals. However, in a similar manner to that in Chapter 7, this avenue is not considered in the economic modelling in this case study. But as shown in the analysis above, waste minimisation and zero waste strategies are viable and more economically more efficient than the 'do-nothing' strategy, i.e. landfilling waste.

It has been observed by the researcher that the implementation of a penalty/incentive scheme will likely require a robust contractual agreement between project partners as well as a comprehensive waste management/waste minimisation plan. This means such a penalty/incentive scheme, if introduced, may increase the cost component significantly compared to the 'landfill' strategy. But as shown in the analysis above, the economic benefits offered by the 'waste minimisation' and 'zero waste' strategies can outweigh the additional administrative costs of a waste minimisation strategy. As such, there may be room to include a penalty/incentive scheme. However, since this area is outside the scope of the study, there is no way to confirm or deny this observation. This is indeed an opportunity for subsequent research to explore.

Aside from the direct economic benefits that the client can derive from waste minimisation and zero waste strategies, the client can also obtain many intangible benefits from having 'waste minimisation' and 'zero waste' strategies in their projects.

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These include opportunities to improve their reputations and credentials, thus increasing the opportunities to market their brand/image. In turns, the project creates an opportunity to increase the value for the education provider via highly competitive rentals to tenants. Further, it has been informed that the development has contributed significantly to the increased morale and productivity of staff and students.

As noted in Chapter 6, for the purpose of this study, an assumption on the value of intangible benefits of 'waste minimisation' and 'zero waste' strategies has been made. Specifically, the intangible benefits that the client gets from these strategies are assumed to be \$7,000.

As shown in Section 8.7, with such a conservative value for the intangible benefits, the client can achieved high levels of economic efficiencies. Therefore, it can be concluded that there are indeed values in minimising the C&D waste in this case study.

As both Level 6 waste minimisation and the Level 7 zero waste strategies can offer the client a high level of economic efficiency, the client has imperatives to implement either of these options. However, it has been argued in the analysis section that perhaps Level 6 waste minimisation strategy is the optimal option for the client. Therefore, the research recommends the client to choose this option.

8.8.3. Implications of landfill charge variable

The analyses above have also shown the variable 'landfill charges' can have a significant influence on the management or minimisation strategies of C&D waste. By setting the landfill charges at \$150 per tonne, this study has observed major impacts this variable has on both the cost incurred, and the benefits gained, by the client. This is

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because landfill charges increase, it becomes more expensive to dispose of waste. It is anticipated that this high disposal fees will have a deterrent factor to discourage waste disposal.

At the same time, the client is incentivised to manage and minimise C&D in their projects due to the significant economic benefit potentials offered by such practices. Potential benefits to the clients include, but not limited to, cost-savings and resale of excess materials. In a way, the variable 'landfill charges' has a positive influence on the benefits obtained by the client from their waste management/waste minimisation strategies. This finding is important because it confirms the long-held belief in the New Zealand construction industry that increasing landfill charges will induce behavioural change in the industry regarding its waste minimisation.

8.8.4. Limitation

Through this case study, the research has demonstrated that the proposed framework is could be applied to a single waste stream. Coupled with findings in Chapter 7, this study has shown the flexibility of this economic evaluation framework.

However, the weakness of this study is it currently focuses on only one fixed area: landfill fee of \$150 per tonne of waste. This makes this study one-dimensional. There are many factors that can have significant effects on the success of a waste minimisation strategy. Further, many of such factors are interlinked or inter-related. Thus by making 'landfill fees' the one key focus, this study does not, and cannot, exhibit the true extend of the problem related to C&D waste minimisation in New Zealand. However, this chosen paradigm is necessary given the limited time and scope imposed on the study reported in this thesis. Subsequent studies can be carried out to establish

other variables that have significant effects on the success of a waste minimisation strategy. This will help the industry to understand these variables better and how they can affect a zero waste aspiration in New Zealand construction.

8.9. Operatives in C&D Waste Minimisation

It is contended that everyone involved in the project has an important role to play to ensure a waste minimisation strategy meets its intended objectives. This section briefly discusses the roles and responsibilities of key participants. Although the focus of the discussion rests on the design phase, their respective responsibilities also extend to the construction and operation stages.

8.9.1. Client and Project Manager (client side)

The client and the project manager in this case study is one and the same. The client used their internal staff to look after the project so they understand the organisation's requirements well.

It was informed by the client in this case study that they worked hard to ensure their objectives were met. As a result, they were involved in all stages of the development, including construction.

However, it was informed by the client that they had the greatest influence on the waste minimisation agenda at the design stage. It is at this stage that they could set project targets and strategies, including a waste minimisation strategy.

8.9.2. Designers

Designers such as architects and engineers have an important role in the waste minimisation strategy. Efficient designs can help reduce wastage in the construction phase. In this case study, the client employed their internal staff to carry out architectural design while using external engineering firms to undertake engineering designs.

The client realised the importance of collaboration between organisations in the design team, as each commercial design entity would have their own agendas. As such, efforts were made to ensure such collaboration worked.

Further, the designers were involved in supervision of the building construction to ensure all systems work as designed and that wastages could be minimised accordingly.

8.9.3. Contractors

Contractors have a major role in ensuring all waste minimisation goals are met during construction. This role can also extend to the design stage, although their involvements can be more limited than other participants such as the designers.

During design, the contractors can be involved to provide inputs on the constructability and areas which they think waste could be minimised. The involvement of the contractor during the design phase can provide significant value to the overall design. They can bring in with them a wealth of knowledge and experience regarding constructability and building systems. In turns this can ensure the building is functional while meeting waste minimisation targets in the construction stage.

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For contractors, it is possibly at the construction phase that they have the greatest influence on waste minimisation. The contractors would be responsible for every aspect of the construction stage. This means they have the power to make sure C&D waste is properly sorted, reused or recycled. This could be done through influencing onsite operatives and subcontractors. Contractors may have opportunities to identify areas to reduce waste further when construction commences.

However, from a commercial perspective there must be incentives for the contractors to undertake waste minimisation practices onsite. One such incentive is for the client to engage the contractors early and get them involved in the design stage. By being involved in the design phase, the contractors have an opportunity to earn extra incomes aside from their tendered prices. Although the money earned through this involvement may be relatively small compared to the tendered prices, this early engagement allows the contractors to have a good understanding of the project. It also gives the contractors a sense of ownership of the project, which in turns encourages the contractors to undertake waste minimisation during construction.

8.10. Validation Summary

Telephone interviews were made with the same professionals who participated in the phase one interviews. However, because several professionals have changed jobs or were unable to answer phone calls, 15-minutes telephone interviews with available participants were restricted to only three of the original seven professionals (numbers 1, 5 and 6). Interview questions and interview transcripts can be found in Appendix C and Appendix D, respectively.

In general, the feedback from the participants has helped confirm the findings of this research:

- it is not possible to reuse and recycle all C&D waste (i.e. zero waste).
- optimal range for waste reduction rate obtained in this study (71% - 78%) was realistic and is achievable in the New Zealand construction industry
- design-out-waste is an effective way of minimising C&D waste
- incentives can help reduce, reuse and recycle C&D waste

8.11. Conclusion

This chapter has demonstrated the applicability of this economic framework to the evaluation of waste minimisation strategies for the brick waste stream in a refurbishment project. The results obtained show that the client can get significant values from waste minimisation. In addition, other parties involved in the waste minimisation strategy can also obtain some economic benefits. Finally, waste minimisation strategies were analysed so a recommendation on an optimal waste minimisation strategy for this case study could be made.

This case study also explored roles and responsibilities of participants of the waste minimisation strategy to provide a good understanding of the contributing factors to a successful waste minimisation strategy.

This case study further demonstrated the flexibility of the proposed economic framework with its application to a single waste stream. In turns, an understanding of this flexibility allows the framework to be used to evaluate the values of C&D waste minimisation in New Zealand.

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9.1. Introduction

This thesis has contributed to the understanding of C&D waste minimisation economics in New Zealand. The thesis has explored areas relevant to C&D waste minimisation and zero waste. Subsequently an economic evaluation framework was developed to identify optimal waste minimisation strategies for building construction projects. It is intended that further research can be undertaken to refine and improve this framework.

The purpose of this chapter is to provide a research overview and summarise key findings and conclusions regarding the specific research questions and objectives. It also states the contribution to knowledge this study has made as well as recommendations for future research.

9.2. Conceptual and Theoretical Challenges

Chapter 1 outlined the problem associated with C&D waste in construction worldwide as well as that in New Zealand.

Due to a lack of theoretical basis for zero waste, Chapter 2 introduced a conceptual model to represent the theoretical construct of zero waste in construction setting. This conceptual model allowed for a systematic review of literature related to C&D waste minimisation and zero waste. In turns, the literature review provided a good understanding of issues and challenges in C&D waste minimisation as well as necessary actions required to address those issues.

It was revealed in Chapter 2 that the most important factor in C&D waste minimisation is the economics of such a strategy. This finding is important for New Zealand.

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Currently the country is experiencing a construction boom in Auckland and Christchurch. It is therefore essential that it has appropriate strategies to address C&D waste in order to meet its long-term sustainability goals.

In the past, New Zealand often looked to the United Kingdom (UK) for guidance and adopted their strategies accordingly. However, in C&D waste minimisation, this strategy may not work, as the underlying dynamics of the construction industries in the UK is different to that in New Zealand. For instance, while the UK construction can get access to cheap labour from Eastern Europe relatively easily due to its connectedness with Europe, it is comparatively more difficult for New Zealand construction to access cheaper labour due to its location in the middle of the Pacific Ocean. Therefore, to effectively address its C&D waste problem, New Zealand must develop its own C&D waste minimisation strategy. Given the importance of economic considerations, the first step is to develop a framework to evaluate the economics of C&D waste minimisation strategies in the New Zealand construction industry.

9.3. Research Problem

Currently there is a lack of tools to comprehensively evaluate the economics of C&D waste minimisation strategies in New Zealand. This means appropriate stakeholders in construction are not well-informed of the values of waste minimisation and waste minimisation strategies. In turns this lack of understanding can have detrimental effects on the efforts to minimise C&D waste.

The problems investigated in this research may be summarised as:

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- Currently there is a lack of an understanding of factors affecting C&D waste minimisation strategies in New Zealand
- Currently there is a lack of an established economic evaluation framework to evaluate and establish optimal waste minimisation strategies for building projects

9.1. Restatement of Research Objectives

The research objectives are:

1. To identify factors that may have significant effects on C&D waste minimisation in New Zealand construction
2. To identify actions needed to encourage the uptake of C&D waste minimisation in New Zealand construction
3. To formulate a framework to evaluate the economics of C&D waste management strategies available to New Zealand construction

9.2. Objective One

9.2.1. Objective Statement

TO IDENTIFY FACTORS THAT MAY HAVE SIGNIFICANT EFFECTS ON WASTE MINIMISATION IN THE NEW ZEALAND CONSTRUCTION INDUSTRY

The review of literature in Chapter 2 has revealed there are many factors that can affect a waste minimisation strategy. These include external factors (such as government regulations and economic conditions), internal factors (such as the industry's

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fragmented nature and technology). These factors have been discussed and studied in great details overseas. Further, they are postulated to have significant effects on potential successes of C&D waste minimisation strategies. However, in New Zealand there is a severe the lack of knowledge on the economic impacts of these factors on waste minimisation strategies. In turns this is perhaps the main impediment for New Zealand to undertake meaningful steps to address C&D waste.

In this study, efforts have been made to understand factors affecting C&D waste minimisation in New Zealand construction. This is important because without this knowledge, it is difficult to develop meaningful economic models to evaluate C&D waste minimisation strategies in New Zealand. Objective One was established for this goal, i.e. to understand these factors from the industry's perspective.

9.2.2. Method

This objective was achieved via an interviewing technique called 'elite interviewing'. This method was undertaken with willing practising professionals in construction. To ensure the study meets all stringent requirements needed for an academic research, the research ethics for approval was sought and approved by the AUT Ethics Committee. The ethics approval letter is included in the Appendix E for reference.

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Semi-structure elite interviewing method was carried out with seven practising professionals in the New Zealand construction industry. These professionals come from different background, including:

- A Project Director with 40 years of work experience in NZ
- A Waste Management Consultant with 35 years of work experience in NZ
- A Senior Architect with 20 years of work experience in both the UK and NZ
- A Senior Project Manager with 20 years of work experience in NZ
- A Construction Manager with 20 years of work experience in the UK and NZ
- A Construction Manager with 15 years of work experience in the UK and NZ
- A Product Category Manager with 11 years of work experience in NZ
construction supply chain management

Overall, the comments and feedback obtained from the interviews were useful for this research. This is due to the fact that all interviewees are senior managers of their respective companies and have had extensive involvements in the New Zealand construction industry. This means there is a wealth of knowledge and experience that the interviewers possess. As a result, not only are their feedbacks useful for this study, to a degree they are a reflection of the understanding within this industry regarding C&D waste minimisation.

The collected data were analysed with the aid of Microsoft Excel™. Using this software, useful information on C&D waste minimisation can be tabulated and extracted from interview results. Subsequently, key variables affecting C&D waste minimisation could be identified.

9.2.3. Findings

9.2.3.1. *Incentives as key drivers for waste minimisation*

It has been shown in the literature that by having an appropriate incentive scheme, significant waste reduction can be achieved (Tam & Tam, 2008). In other words, the (financial) incentives act as a lever to influence the behaviours of companies and operatives in the quest to reduce C&D waste. In New Zealand, there are some incentive schemes, such as the Green Building and Green Star Certification. And they have shown some success in waste reduction.

By contrast, it was found from the interviews that with the current technology and skills, it is possible to reduce and recycle C&D waste in New Zealand. However, the reason the uptake of waste minimisation remains low (and slow) is due to the lack of economic incentives offered to companies. As money a key economic driver in construction, the lack of monetary incentives has discouraged construction companies to adopt C&D waste minimisation practices. As a result, waste reduction is not considered a high priority in building construction projects.

Further, it is contended that having incentive schemes is not enough. There needs to be penalty schemes to the similar effect. A penalty scheme is the reverse of an incentive scheme in that contractors can be penalised for their generation of C&D waste. It is anticipated that a combination of incentive – penalty scheme can strengthen the encouragement/enforcement of waste minimisation in the New Zealand construction industry. This is because on the one hand construction companies can be rewarded for effective management of C&D waste. On the other hand, they could be penalised for ineffective C&D waste management. However, a lack of an incentive – penalty scheme

in New Zealand is a missed opportunity and one which could be addressed in subsequent studies.

9.2.3.2. *Design-out-waste as a key consideration in projects*

The interviews also revealed a common belief in construction that C&D waste minimisation has the greatest impacts at the design stage. This perception is consistent with findings in the literature review (see, for example, Chong et al, 2009; WRAP, 2012). It has been argued by WRAP that design-out-waste should be a key consideration at the design stage in any project to ensure a maximum waste reduction can be achieved (WRAP, 2007, 2009, 2011).

Further, it was indicated in the interviews that having the design-out-waste considerations at design stage do not generally increase the additional cost significantly. Instead, the cost of design-out-waste is so small that sometimes the costs of waste minimisation-focused designs are the same as those of non-waste minimisation-focused designs. However, design-out-waste is not placed high in the project agenda due to the (wrongfully) perception that it would increase the project cost significantly.

This finding is consistent with those of WRAP studies. The finding also shows there is much work to be done to 1) educate people in the construction industry of the value of design-out-waste; and 2) to change the perception that designs with design-out-waste components are more expensive than conventional designs (WRAP, 2007, 2009, 2011).

9.2.3.3. *Landfill charges as key economic factor in waste minimisation*

It was also found from the interviews that landfill charges imposed on C&D waste disposal is a major variable that can have significant effects on the success of a C&D waste minimisation strategy.

Currently in New Zealand, there are no schemes to differentiate or categorise distinct types of waste streams, leading to a situation where it is more economical to dispose of C&D waste than it is to reuse and recycle C&D waste. And this is done at the expense of the environment. Therefore, the interviewees argued that there is an urgent need for a fee charging scheme that is specific to C&D waste in order to change construction's current waste disposal behaviours.

In specific, there is a common perception among the interviewees that the current C&D waste landfill charges are too low. They argued that a higher landfill charge for C&D waste is urgently needed to deter polluters from disposing of C&D waste in landfills.

9.2.4. Implications

9.2.4.1. *Implications for New Zealand Construction*

The interview results show that there is still much work that needs to be done in C&D waste minimisation in New Zealand. The industry's high dependency on the changes of landfill charges means that it is vulnerable to the external environments. As such, there is an urgent need for the industry to address this vulnerability.

One approach is for the New Zealand construction industry to establish a closer working relationship with the waste management industry to manage and minimise the C&D waste outputs. This could be achieved through contractual agreements or via collaboration. In the former category, specific requirements regarding C&D waste

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management such as recycling rates can be tightly incorporated and elaborated in the contracts for services. This can ensure construction companies meet their waste management and/or minimisation targets. However, the downside of this option is the cost, as waste management companies will likely charge construction companies a premium for such services. In the latter category, construction companies are likely required to establish a long-term working relationship with waste management companies to ensure the collaboration in C&D waste management is beneficial for everyone. Although this option may be less costly to construction companies compared to the former, it is more time-consuming, as it requires both parties to spend time and effort to work towards a common goal.

Another approach is for the industry to create an internal industry-driven decision-making mechanism to promote and encourage C&D waste minimisation in NZ construction. This is because it has been observed that for any construction-related programme to be sustainable, it must be driven internally by the industry itself. Such a decision-making framework can be helpful for the industry, as it provides a platform for the industry as a whole to work towards a common goal of minimising C&D waste. Moreover, such a framework can help the industry to create and drive initiatives such as an industry-specific incentive-and-penalty scheme in order to achieve this goal.

9.2.4.2. *Implications of this Study*

The information obtained from the interviews was particularly helpful for this study. Based on this information, a contextual framework representing the economics of C&D waste minimisation in New Zealand construction was developed.

9.3. Objective Two

9.3.1. Objective Statement

TO IDENTIFY ACTIONS NEEDED TO ENCOURAGE THE UPTAKE OF ZERO WASTE IN NEW ZEALAND CONSTRUCTION

9.3.2. Method

The approach undertaken to achieve Objective Two is similar to that in Objective One. Specifically, one-on-one semi-structured elite interviews were employed to help identify necessary actions required to encourage the uptake of waste minimisation in New Zealand construction. Further, the interviews were carried out with the same seven practicing professionals in the NZ construction industry. Interview results in this objective were used as basis for the modelling process.

9.3.3. Findings

9.3.3.1. *High landfill charges as deterrent to C&D waste disposal*

As briefly mentioned in Section 9.2.3.3 above, there is a consensus among interviewees that there is a need for New Zealand to increase landfill charges. The rationale for this suggestion is that since money is a key factor in decision-making in construction, a high fee for C&D waste disposal can, and will, force companies in the construction industry to reconsider their current practice of disposing of C&D waste to landfills. This is because high landfill charges will make disposing of waste in landfills become an expensive exercise which will affect companies' financial bottom line. Over

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the long term, it is anticipated that this will make the construction industry more responsible for its actions around C&D waste.

The consensus from the construction professionals is that the landfill C&D waste disposal fee of \$150 per tonne is appropriate. It is felt that the current C&D waste landfill charge of \$10 per tonne is too low and is an impetus for construction companies to continue the practice of dumping waste in landfills. It is anticipated that a 1500% increase in landfill charges will change this behaviour because this high fee will make it very expensive for construction companies to continue their current practice: disposing of waste in landfills.

9.3.3.2. *Rigorous waste minimisation strategies equals large cost savings*

It was revealed in the interviews that there are many benefits associated with C&D waste minimisation, including direct terms (such as cost savings) as well as indirect terms (such as improved reputation). Further, all benefits have their associated values; and such values can be monetised or cost otherwise. Therefore, these benefits need to be evaluated accordingly.

There are many materials available in New Zealand outlining this fact (BRANZ, 2009; ITM, 2013). However, the fact that C&D waste remains a large portion of all landfill waste means that perhaps this is due to the attitude of operatives within the construction industry regarding C&D waste. It has been shown in overseas studies that attitudes and perceptions around C&D waste can have significant influence on the actions of C&D waste minimisation (Teo & Loosemore, 2001; Kulatunga et al, 2006; Begum et al, 2006; Afroz et al, 2008). As such, there needs to be a comprehensive

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educational framework setup to provide a good understanding of issues with C&D waste, and benefits of C&D waste minimisation.

For such an ambitious programme to work, there needs to be commitment from key stakeholders in construction. These key stakeholders include, but not limited to, relevant government departments, key industry bodies, construction companies and education providers. Further, these key stakeholders must work collaboratively to ensure tangible outcomes around C&D waste minimisation can be achieved. Such an educational programme can be complex and costly to set up and run, as it involves many parties with differing interests. However, it is anticipated that such an educational programme will provide significant benefits to the construction industry via reduced wastages and increased cost savings. Longer term, this in turns can help the New Zealand construction industry to be more sustainable.

9.3.4. Implications

9.3.4.1. *Implications for NZ Construction*

It was generally acknowledged by the interviewees that in the short-term, the high landfill charging fee of \$150 per tonne will deter polluters from disposing C&D waste into landfill. This is because companies will avoid sending waste to landfills in order to save costs.

However, at the same time they may find other ways to get rid of the C&D waste. And this may lead to increased illegal dumping of C&D waste materials.

Therefore, appropriate strategies are needed to minimise adverse environmental effects that may arise from this proposal. Over the long-term, it is anticipated that construction

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companies will adjust to this new working environment and minimise their C&D waste accordingly.

It is also anticipated that as more C&D waste being recycled and repurposed, it could also create additional economic opportunities such as second-hand markets for recycled construction materials or niche recycling markets of companies. Not only do such opportunities help stimulate and encourage waste minimisation actions but they also have a role in creating additional employment opportunities and additional wealth for communities. In this sense, the construction industry has an indirect contribution to the economic development of the wider society.

9.3.4.2. *Implications of this Study*

As previously stated, the aim of this research is to understand the economics of a zero waste strategy in the New Zealand construction context and to identify the most economically optimal waste minimisation strategy in building projects. To achieve this goal, the current study develops an economic evaluation framework based on feedback obtained from Objective One and Objective Two.

As identified in these two research objectives, 'landfill charge' is the key variable affecting C&D waste minimisation strategy in New Zealand. As a result of this finding, the variable 'landfill charge' is incorporated into the modelling process. Further, the landfill charge for C&D waste is set at \$150 per tonne. The reason for choosing this value is to test the hypothesis obtained from the qualitative part of the research: 'landfill charge of \$150 per tonne can deter polluters from disposing C&D waste to landfills'.

It is anticipated that this approach allows the research to analyse in detail the economic effects of landfill charges on C&D waste minimisation strategies. By understanding this

variable, it is further anticipated that the industry can take appropriate actions and strategies to facilitate a successful C&D waste minimisation programme in New Zealand.

9.4. Objective Three

9.4.1. Objective Statement

TO FORMULATE A FRAMEWORK TO EVALUATE THE ECONOMICS OF C&D WASTE MANAGEMENT STRATEGIES AVAILABLE TO NEW ZEALAND CONSTRUCTION

Based on relevant qualitative data collected from interviews, an economic framework was developed to evaluate the economic values of appropriate C&D waste minimisation strategies, including zero waste. The economic evaluation framework developed in this research is mathematical-based and is based on results obtained from interviews.

In economics, mathematical-based modelling is often employed to fulfil requirement of economic evaluation (see, for example: Doppelt & Dowling-Wu, 1999; Begum et al, 2006; Yuan et al., 2011; Hogg et al, 2011; Till, 2013). Given that the specific requirement of this study is to evaluate the economics of C&D waste minimisation strategies, it makes sense that this study also uses mathematical modelling as basis for analysis. As stated in Chapter 5, the focus of the study is on the client's perspective regarding C&D waste minimisation, with a 'client' being defined as the building owner.

9.4.2. Method

To account for the time value of money, wherever appropriate the study employs a common accounting technique called Net Present Value (NPV). NPV is a powerful method that takes into account the value of money through time based on discount rates. As projects under consideration in this study are multi-year projects, NPV is appropriate to account for time value of money. As a result, NPV would be used wherever applicable in this study.

In addition, the study also employs a wide range of economic evaluation techniques such as Economic Impact Analysis (EIA), Benefit-Cost Analysis (BCA) and Cost Effective Analysis (CEA) to help analyse the results. The combination of these economic evaluation techniques helps the study convey its results effectively.

To test the applicability of the models developed, the study employs 'case study' research. Two case studies were chosen: a new construction of an education centre and a refurbishment of an office building. The first case study focusses on the economic evaluation of six waste streams whereas the second case study focuses on one waste stream (brick waste). The reason for this choice is to demonstrate the flexibility of the framework developed in this research: the framework could be used to evaluate either a single waste stream or a range of waste streams.

The research considers seven waste strategies. These strategies range from the most basic strategy (such as landfilling waste) to the most ambitious level (such as zero waste). The rationale for the chosen range of waste strategies for this research was offered in Chapter 6.

Table 47: C&D Waste Minimisation Strategies in this Research

Waste Strategy							
Strategy	1	2	3	4	5	6	7
Description	Waste to Landfill	Waste Reduction	Waste Reduction	Waste Reduction	Waste Reduction	Waste Reduction	Zero Waste
Reduction Rate	0%	5%-10%	11%-30%	31%-50%	51%-70%	71%-95%	100%

The economic evaluations of these waste streams were offered in Chapter 7 (Case Study 1) and Chapter 8 (Case Study 2).

9.4.3. Findings

Chapter 7 and Chapter 8 have shown that the economic evaluation framework developed in this study is flexible and capable of evaluating the economics of wide range of waste streams under different C&D waste minimisation strategies. This section summarises key findings in this study.

9.4.3.1. Cost Component of Baseline Strategies

The baseline strategy for case study 1 is Level 5 waste minimisation strategy while baseline for case study 2 is Level 1 waste strategy. In both cases, the disposal of C&D waste is not cost-effective. This is mainly due to the major adverse impacts this operation has on the environment: C&D waste is often not treated or processed before being disposed of. Thus it has a high potential to create major environmental and health hazards in the future. In this study, these are considered non-cost attributes of waste disposal.

Both the baseline strategies show high levels of costs for C&D waste disposal. This is due to the fact that there remains a significant amount of C&D waste in the baseline

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strategies. Coupled the high landfill charge of \$150 per tonne, the costs associated with collecting and landfilling the waste remain high.

Although the analysis shows that the costs of design-out-waste in both baseline strategies are lower than those of other strategies in their respective cases, when taking non-cost attributes into account, the total cost of waste disposal may end up being much higher than its current level.

Therefore, due to this high potential cost, it is recommended that the client should consider other waste minimisation strategies.

9.4.3.2. Cost Component of Level 6 and Level 7 Strategies

At these levels, the 'costs of design-out-waste and waste strategy' are significantly higher than those in the baseline strategies of both case studies. The higher costs of these components are due to the high compliance cost that the client must spend to ensure high level of waste reduction. In particular, they must also spend significant money to establish waste minimisation strategies for the projects and ensure all project partners follow and adhere to the waste minimisation strategies. Also under Level 6 and Level 7 strategies, the client must spend more money on design-out-waste than they do in the lower level strategies.

Further, since these strategies require a significant amount of double-handling of waste, the cost with such activities must increase accordingly. The double-handling of waste comes from the fact that waste is transported twice: first, waste must be handled from collection point (i.e. construction site) to waste management facilities. Subsequently waste must be handled at waste management facilities to get rid of any residues that cannot be recycled or salvaged. This is the unique (and costly) feature of this strategy.

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In the 'landfill' strategy, all waste is disposed of to landfill regardless of their reusability or salvage values. However, in the zero-waste strategy, all waste is recycled or reused thus eliminating the need to transport waste from waste management facilities to dump site. As a result, careful consideration must be given to this strategy, as the client may end up paying twice for the transportation of waste.

The 'zero waste' strategy requires rigorous waste minimisation undertaking. As a result, the waste generated under this strategy is less than that under the other alternative strategies. This is true in both case studies. Moreover, with the high recycling and reuse rate (100%), this strategy offers the client a cost-effective option. This is because in the 'zero waste' strategy less waste is produced, thereby saving the client on materials. With less waste produced, the client spends less on transportation and processing costs while deriving earnings from sales of reused/recycled materials to offset the cost of purchasing original materials.

Similarly, Level 6 waste minimisation strategies can offer the client a near identical cost efficiency as the zero-waste strategy. However, unlike the zero case, the Level 6 waste minimisation is achievable due to their lower requirements for waste reduction rates than its zero waste counterparts. Level 6 strategy of case study one requires a waste reduction rate of 78% while Level 6 strategy of case study requires a waste reduction rate of 71%. In practice, both these waste reduction rates are achievable (and in fact have been achieved in real situations). Further, the costs associated with achieving these levels are much lower than those for Level 7 (zero waste) strategy. But the returns between the two levels for both case studies are similar. And therefore, it can be argued that Level 6 strategies in both cases are more economical than the Level 7

strategies. The cost-effective of Level 6 strategy is a compelling argument for its implementation in construction projects.

9.4.3.3. *Benefit Component of Baseline Strategies*

Both case studies show that there is little benefit to the client in the 'landfill' strategy. By dispose of the C&D waste, the clients get rid of all potential cost savings that could be derived from it. This includes opportunities to on-sell the processed materials to the secondary markets to offset the costs of purchasing the original materials.

Although in many situations it could be economical to dispose of the waste, as the additional costs associated with processing waste may outweighs the benefits derived from it. However, in the case studies considered in this thesis, the benefits of recycling waste outweigh the cost of landfilling C&D waste. This is a compelling case to consider C&D waste minimisation as a better alternative to 'landfilling' waste.

As the baseline strategy of case study one is a Level 5 waste minimisation strategy, the degree of benefits that the client can derive from this case is much higher than those in the baseline strategy of case study two (since the baseline of this case study is Level 1). However, in both cases Level 6 waste minimisation strategy is the ideal strategy for this case study.

9.4.3.4. *Benefit Component of Level 6 and Level 7 Strategies*

The benefits offered by these two strategies are much higher than those offered by their respective baseline strategies. It can be observed that with a high landfill charge, the clients gain significant economic benefits. This is because as more waste is diverted from landfills, the client can save more on waste disposal costs. This observation demonstrates a positive relationship between 'landfill charges' and 'economic benefits'.

These arguments show a compelling business case for the clients to implement a waste minimisation strategy.

However, there is one area that this study did not sufficiently cover, that is the lack of explicit evaluation of intangible benefits for the clients. There is a common trend in both case studies: the clients have received significant values from their projects but they did not quantify and evaluate such intangible benefits in their respective projects. This is a missed opportunity and one which requires further research.

9.4.3.5. BCA of Baseline Strategies

The Benefit-Cost Ratio (BCR) is the ratio between the benefit component and the cost component of a strategy. Due to the fact there is no benefit to the clients under the 'Landfill' strategy, the BCR of this strategy is 0%. This means the 'landfill' strategy is not an economically efficient option. From an economic perspective, the client should avoid this strategy and consider other options that can offer better value for money.

By contrast, the baseline strategy for case study one shows a relatively high degree of economic efficiency (BCR = 71%). This is perhaps due to the high level of investment that the client has spent in this strategy to ensure at least 51% of their C&D waste outputs could be diverted from landfills. As argued in Section 9.4.3.3 above, despite its relatively high economic efficiency, the Level 5 strategy of Case Study One does not deliver the optimal economic returns and thus it can be improved.

9.4.3.6. BCA of Level 6 and Level 7 Strategies

The BCRs of both these levels show near identical economic efficiency rates (105% and 131% for Level 6 and Level 7 in case study 1 and 94% and 97% for Level 6 and Level 7 in case study two).

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It has been observed that a high landfill charge of \$150 per tonne brings a high cost of waste disposal. This high cost of waste disposal is perhaps the impetus for the clients to look for alternative options to landfilling waste. An alternative is to minimise waste. This means there is a need to identify an optimal strategy that could deliver the client a high level of returns (benefits) for a reasonable price (costs).

As more waste is managed and minimised through waste minimisation strategies, the clients also receive more benefits through cost savings and material savings. There is a cost associated with the implementation of the 'waste management' strategy. However, the benefits received by the clients can help recuperate some of this cost. This explains for the increasing BCRs in all waste minimisation strategies in both case studies.

As more stringent requirements for waste minimisation are required, more aggressive steps are needed to minimise waste. Steps that the clients employ can be a combination of management methods including, but not limited to:

- Value Engineering: to realise potential values and areas that can be exploited to deliver added value to waste minimisation strategy
- Just-in-Time (JIT): to ensure right amount of materials delivered to site when needed in order to minimise wastage
- Total Quality Management (TQM): to ensure all work packages are completed to the desired quality to minimise rework and double-handling

This culminates to the 'zero waste' strategy. Hence 'zero waste' is the ultimate goal of the 'waste minimisation' strategies. In the zero-waste strategy, the disposal costs decrease sharply due to the elimination of the cost of transporting to landfill.

However, the compliance costs associated with the implementation of the zero waste strategy are significantly higher than those in Level 6 waste strategy. But the rates of return (BCRs) between the two strategies remain similar.

9.4.3.7. Optimal Rates of Waste Minimisation

This study has made two discoveries. The first discovery is BCR is an appropriate metric to assess the comparative economic efficiency of C&D waste minimisation strategies. The second discovery is an establishment of the optimal C&D waste minimisation rates. The second discovery will be discussed in detail in this section.

From an economic perspective, Level 6 strategy in both case studies is the optimal waste minimisation strategy, as it delivers the optimal value for money to the clients in the two cases considered in this research. Based on this result, it can be argued that the optimal rate for C&D waste minimisation lies between 71% and 78%. The first figure (71%) comes from the second case study while the second figure (78%) originates from the first case study. As shown in both case studies, any waste minimisation rates higher than these base figures only add marginal benefits to the clients while at the same time incurring higher costs. Therefore, these base figures are optimal minimisation rates for each case study; and collectively they form a basis for an establishment of the optimal C&D waste minimisation strategy for this research, namely Level 6.

However, this result is based on the limited sample used in this research (two case studies). As a result, further research is required to validate this finding. Nevertheless, this finding has established a basis for future investigations in C&D waste minimisation. This is based on the fact that no previous studies have made this discovery.

9.4.4. Implications

9.4.4.1. *Uniqueness of the research*

The economic evaluation framework developed in this study is unique to the New Zealand construction industry for several reasons.

First, it was developed based on interviews with New Zealand-based practising construction professionals with many years of experience. The feedback received from these professionals has ensured that the framework is applicable to the New Zealand's situation in relation to C&D waste minimisation.

Second, investigations into the economics of C&D waste have not been previously undertaken in New Zealand. A number of previous studies have outlined potential benefits of C&D waste management (Snow and Dickinson, 2001; Kazor and Koppel, 2007; Kestle & Rimmer, 2010; ITM, 2013; BRANZ, 2014). However, no studies have expressly evaluated the economics of a zero-waste strategy. This is knowledge gap in New Zealand construction that needs to be filled urgently; and it is the objective of the study reported in this thesis. To this end, this study is the first of its kind in New Zealand to investigate the zero-waste paradigm of economics of C&D waste minimisation.

Third, the framework was designed to be flexible and applicable to various waste streams and situations in New Zealand. To validate its flexibility and applicability, the framework was applied to two case studies of different natures to evaluate a range of waste streams. The results show the framework was able to achieve its designed objectives. In other words, the framework could be used to evaluate either a single waste stream or a multitude of waste streams. Further, the framework can assess the economics of various waste strategies, ranging from the basic strategy (such as

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landfilling waste) to the advanced waste minimisation strategy (such as zero waste). Overall, this New Zealand-centric economic evaluation framework has allowed for its applications to be unique to the New Zealand cases and situations.

Finally, the research has established the optimal rates C&D waste minimisation strategy and optimal waste minimisation rates in New Zealand. It was found that the optimal rate for C&D waste minimisation strategies in the building industry lies between 71% and 78% (Level 6 strategy). Although this finding was based on a limited sample (two case studies), it has nonetheless established a basis for future research in C&D waste minimisation. This is since no previous studies have made this discovery and established such a detailed base figure.

9.4.4.2. Collaboration as a key to desired waste minimisation outcomes

Chapter 7 and Chapter 8 have shown that there needs to be a collaborative working environment to ensure a successful waste minimisation objective can be achieved. In this collaboration, the client should be proactive in working with other stakeholders such as architects, engineers, contractors and specialist waste management sub-contractors to establish and execute an overall waste strategy.

The economic modelling in Chapters 7 and 8 has confirmed a long-held belief in New Zealand construction that the variable 'landfill charges' indeed has significant influence on a waste management programme in New Zealand. This means in order for all stakeholders to get value out of a waste minimisation programme, there needs to be a close working relationship between construction companies and specialist waste management companies. This close working relationship can foster opportunities such

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as a creation of a second-hand market whereby construction companies can provide specialist waste management companies feedstock for their second-hand markets.

Overall, in this collaboration framework, effort must be spent to monitor, track progress to ensure all parties follow the plan and to review waste management plan as the project progresses to ensure it is up-to-date in all circumstances. In all cases, there is a cost associated with maintaining this collaboration as well as the implementation of a waste management strategy. However, as shown in Chapters 7 and 8, the benefits that the clients can derive from such a strategy outweighs this cost. Many of the benefits that the clients get are intangible and unquantifiable. They include:

- opportunities to improve reputations and credentials to increase the opportunities to market the clients' brands and images
- contribution to the increased morale, well-being and productivity of people working in the buildings
- an opportunity to increase the value to the clients via potential (highly competitive) rentals

The quantification of these intangible benefits is highly complex and one which constitutes a different study. Due to the limited time and scope of this research, it is not possible to explore this area. For the purpose of this study, assumptions regarding the intangible benefits of 'waste management' and 'zero waste' strategies have been made for both case studies. Despite the fact that the assumed economic values for these intangible benefits are conservative in both cases, the analyses in Chapters 7 and 8 showed the clients achieved high levels of economic efficiency for both 'waste

management' and 'zero waste' strategies. It can be, then, concluded that there are values in minimising C&D waste.

9.5. Limitations

While the framework developed in this study is flexible and can be used to evaluate the economics of different C&D waste minimisation strategies, there are limitations in its methodology.

First, the study only considers one factor that can have significant impacts on the success of a waste minimisation strategy in NZ construction: landfill charges. This factor was identified in the research as important drivers in a waste minimisation strategy. However, this sole focus on this one variable makes this study one-dimensional. There are many interacting factors that can have significant effects on the success of a waste minimisation strategy. Thus by making 'landfill charges' the one key variable, this study does not, and cannot, exhibit the true extent of the problem related to C&D waste minimisation in New Zealand. This is one major weakness of this study.

Second, the economic modelling undertaken in this study is stationary, i.e. nothing changes under any circumstances. This is the underlying assumption underpinning this study. Although this assumption helps simplify the modelling process, it is not realistic, as there is always a degree of uncertainty involved in a C&D waste management strategy. As a result, subsequent studies can be carried out to establish other variables that have significant effects on the success of a waste management strategy. These variables may be tested using advanced techniques for uncertainty analysis such as Monte Carlo analysis to analyse their behaviour under changing circumstances (i.e.

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under uncertainty). This will cater for a better understanding of variables or factors affecting New Zealand construction's zero waste aspiration.

Third, although the study acknowledged there were many intangible benefits associated with a C&D waste management strategy, it did not evaluate the economics of such intangible benefits. Instead, assumptions regarding the economics of the intangible benefits were made. Although these assumptions simplified the problem at hand significantly, they may not be realistic; thus rendering the study for potential scrutiny. Furthermore, without a method to explicitly evaluate the intangible benefits, any attempt to emulate this study is difficult. This is because assumptions regarding these intangible benefits must be made every single time; hence making the framework unreliable. This is a missed opportunity and one which subsequent researches could investigate in detail.

Finally, the study currently focuses on the economics of C&D waste minimisation from the client's perspective. Although this choice is sufficient for the purpose of this study (i.e. to demonstrate the applicability of the economic framework developed in this study), it does not cover all aspects relating to C&D waste minimisation in the New Zealand construction industry. There are many parties involved in a construction project. They include, but not limited to, clients, architects, engineers, quantity surveyors, land surveyors, contractors, specialist sub-contractors and waste management sub-contractors. Each of the parties mentioned above has a different perspective, a different objective and a different focus relating to C&D waste management. But they all contribute to the success of an overall project C&D waste minimisation strategy. By focusing on the client side is a good start, as they ultimately pay for everything in the construction project. However, this choice may be too narrow

and does not cover or reflect all aspects involved in a C&D waste management strategy. Therefore, there is a need to investigate the economics of C&D waste minimisation from other parties' perspectives and this could be catered for by subsequent researches.

9.6. Future Research

Overall, this study has achieved its stated objectives. Specifically, the study has demonstrated that the economic framework is flexible and can be applied to various waste streams. However, based on the limitations identified in Section 9.5, some suggestions for future work can be made.

First, there is an urgent need to incorporate the incentive – penalty models of this framework. Although this current research does not include this aspect, it is considered an important driver for the uptake of C&D waste minimisation in New Zealand. As a result, there are opportunities for future research to investigate an incentive – penalty scheme in detail. It is anticipated that by being able to incorporate the incentive and penalty models, the economic evaluation framework will become more mathematically and economically sound.

Second, to enhance the value of the study being reported in this thesis, there may be a need to incorporate uncertainty into the modelling process. As uncertainty is present in all industrial processes, having it built into the modelling process can help strengthen the framework developed in this study significantly. Further, the information derived from the uncertainty models can help cater for improved strategies to address C&D waste.

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To enhance this study further, effort can be spent to investigate and quantify the intangible benefits associated with C&D waste management. This is a missed opportunity and one which needs to be filled urgently in order to strengthen the value of this study.

There is also a need to verify (or disprove) the proposed optimal waste reduction rates found in this research. The optimal waste reduction range of 71%-78% was based on the two case studies used in this research. Further, it was a product of the economic evaluation framework developed for, and by, this study. As such, there may be errors inherent in the assumptions and findings. In order to confirm this proposed optimal waste reduction range, or otherwise, there is a requirement for further research to be undertaken urgently. Any further results will provide an improved understanding of this subject matter and in turns advance the knowledge in C&D waste minimisation economics.

Finally, there is an urgent need to investigate the economic values of C&D waste minimisation from other stakeholders' perspectives. These stakeholders include, but not limited to, clients, architects, engineers, quantity surveyors, land surveyors, contractors, specialist sub-contractors and waste management sub-contractors. By understanding the economic perspectives of these stakeholders on C&D waste minimisation, appropriate strategies can be developed to ensure the sustainability of a C&D waste minimisation strategy.

9.7. Contribution to Knowledge

Given that there are few studies investigating C&D waste minimisation and C&D zero waste in New Zealand, this study has contributed to the body of knowledge in the following ways:

1. The research has developed a bespoke methodology to achieve research objectives
2. The research has established a conceptual economic model for C&D waste minimisation that is appropriate for the New Zealand construction industry. This conceptual model can be used as a roadmap to chart necessary pathways to minimise C&D waste
3. The economic evaluation framework developed in this research is flexible and applicable to a range of waste streams and waste minimisation strategies. This helps advance understanding in the area of C&D waste minimisation economics
4. The research established a methodology to identify optimal C&D waste minimisation strategies for clients in building projects
5. As this research is the first in New Zealand to develop a comprehensive framework to evaluate the economics of C&D waste minimisation, it can be an impetus for further research in this area in New Zealand
6. This research established optimal rates for C&D waste reduction in the New Zealand building sector. The optimal waste reduction rate is between 71% and 78%. This is a major contribution to knowledge because no studies have identified such detailed waste reduction rates as this research.

9.8. Research Finding Evaluation

This section evaluates and associates key findings of this study with the stated research aim, research objectives and research questions. The evaluation is demonstrated in Tables 49-51.

Table 48: Associating Research Findings with Research Questions

RESEARCH QUESTION NUMBER	RESULT
1	Addressed
2	Addressed
3	Addressed
4	Addressed

Table 49: Associating Research Findings with Research Objectives

RESEARCH OBJECTIVE NUMBER	RESULT
1	Achieved
2	Achieved
3	Achieved

Table 50: Associating Research Objectives with Research Aim

RESEARCH AIM	ACHIEVED
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9.9. Research Conclusion

This research has achieved its research aim in establishing a base understanding of C&D waste minimisation economics in the context of New Zealand construction.

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Through literature review, this research has established an understanding that while construction plays an important role in national growth and wealth worldwide, it also created significant unwanted and costly adverse effects in the process in forms of C&D waste. It was found that there are the costs of C&D waste in forms of environmental costs (such as resource depletion and pollution), social costs (such as health and wellbeing of communities) and economic costs (such as remedial costs to manage effects of C&D waste or additional investments to expand landfill sites). These costs are significant and have significant impacts on construction's long term sustainability aspirations. Therefore, there is an impetus for construction and society in general to address C&D waste urgently. As money is a key consideration in construction, there is an immediate need to investigate C&D waste minimisation economics. This was the rationale for this study.

The literature review also showed that although there are a number of economic models concerning C&D waste management and minimisation, these models could not sufficiently address two key issues: 1) how to identify the optimal C&D waste minimisation strategies and 2) what is the optimal C&D waste reduction rate?

Subsequently, this research employed a mixed-paradigm approach to address this knowledge gap. The mixed-paradigm approach was employed to help the research overcome the lack of empirical information on the research subject matter. Further, it also strengthened the theoretical perspective of the research, as it allowed for the development of a framework that is appropriate for, and applicable to, the case of New Zealand construction.

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As shown through the modelling process, there are significant benefits that can be derived from the implementation of C&D waste minimisation, including tangible returns (in forms of cost savings), as well as intangible potentials (such as increased reputations or potential opportunities for rentals). Although the costs associated with the implementation of C&D waste minimisation are higher than otherwise, the benefits often outweigh such costs. Therefore, there are economic imperatives for companies to adopt and implement C&D waste minimisation in their projects.

It was found, through modelling, that optimal waste reduction rate ranged between 71% and 78%; and the optimal waste minimisation strategy in New Zealand is Level 6 strategy (with reduction rate between 71% and 80%).

However, one must be careful when interpret the above findings because these results are specific to this research only. And further investigations are required to confirm (or otherwise) the validity of the research claim.

Through the development of this robust economic evaluation framework, the study has provided an impetus for future research. Opportunities for future work were identified and listed in Section 9.7.

As the first study investigating economics of C&D waste minimisation and C&D zero waste in New Zealand, this study has made significant contribution to knowledge as outlined in Section 9.8.

Overall, this research has achieved its stated research aim and objectives by successfully answer the research questions. The evaluation of the research was shown in Section 9.9.

REFERENCES

REFERENCES

REFERENCES

- Abdelhamid, M. S. (2014). 'Assessment of different construction and demolition waste management approaches'. HBRC Journal, Vol. 10, p. 317–326
- Abidin, N. Z. & Pasquire, C. L. (2005). 'Delivering sustainability through value management: Concept and performance overview'. Engineering, Construction and Architectural Management Vol. 12, No. 2, p. 168-180
- Abidin, N. Z. (2005). 'Using value management to improve the consideration of sustainability within construction'. PhD Thesis, Loughborough University's Institutional Repository, Loughborough University
- ACENZ & IPENZ (2004). 'Fee Guidelines for Consulting Engineering Services'. Link: <http://www.acenz.org.nz/uploads/Client/Guideline%20on%20the%20Briefing%20and%20Engagement%20for%20Consulting%20Engineering%20Services-1st%20Edition%202004.pdf>
- Adams, J.; Khan, H. T. A.; Raeside, R. & White, D. (2007). 'Research Methods for Graduate Business and Social Science Students'. Response Books, Sage Publishing
- Adams, K.; Johnson, P.; Thornback, J. & Law, C. (2011). 'WASTE: An Action Plan for halving construction, demolition and excavation waste to landfill'. Report for the Strategic Forum for Construction, WRAP
- Adams, K.; Johnson, P.; Thornback, J. and Law, C. (2011). 'Waste: An Action Plan for halving construction, demolition and excavation waste to landfill'. The Strategic Forum for Construction, <http://www.strategicforum.org.uk/pdf/10WasteActionPlan.pdf> (accessed 04 March 2013)

REFERENCES

Adetunji, I. ; Price, A.; Fleming, P. & Kemp P. (2003). 'Sustainability and the UK construction industry - a review'. Proceedings of the Institution of Civil Engineers Engineering Sustainability 156 Issue ES4 Pages 185-199

Afroz, R.; Hanaka, K. & Kurisu, K. H. (2008). 'Factors Affecting Waste Generation and Willingness to Recycle: a Study in a Waste Management Program in Dhaka city, Bangladesh'. FEB Working Paper Series No. 0803, Faculty of Economics and Business, Universiti Malaysia Sarawak (UNIMAS) 94300 Kota Samarahan, Sarawak, Malaysia

Agyekum, K. (2012). 'Minimizing Materials Wastage at the Construction Stage of a Project through the Implementation of Lean Construction'. Master's Thesis. Department of Building Technology, Kwame Nkrumah University of Science and Technology, Ghana

Aiken, A. (2014). 'Lean: Concepts and Realities'. Lanner Group. Link: http://www.lanner.com/en/pdf/lean_and_lanner.pdf

Al Shehaimi, A.; Tzortzopoulos, P. & Koskela, L. (2009). 'Last Planner System: Experiences From Pilot Implementation In The Middle East'. Proceedings for the 17th Annual Conference of the International Group for Lean Construction

Alesii, G. (2006). 'Payback period and internal rate of return in real options analysis'. The Engineering Economist Vol. 51, No. 21

Alexander, S. (2002). 'Green Hotels: Opportunities and Resources for Success'. Zero Waste Alliance

REFERENCES

Al-Hajj, A., & Hamani, K. (2011). 'Material Waste in the UAE Construction Industry: Main Causes and Minimisation Practices'. *Architectural Engineering and Design Management*, Vol. 7, No. 4, p: 221-235

Allen, C.; Gokaldas, V.; Larracas, A.; Minot, L. A.; Tangri, N.; Tyler, B. and Walker, B. (2012). 'On the road to Zero Waste: Successes and Lessons from around the world'. GAIA Report

Altwies, J. E. & McIntosh, I. B. D. (2001). 'Quantifying the Cost Benefits of Commissioning'. Conference: National Conference on Building Commissioning, Hilton at Cherry Hill, Cherry Hill, New Jersey, USA

Amati, M. & Taylor, L. (2010). 'From Green Belts to Green Infrastructure'. *Planning Practice & Research* Vol. 25, No. 2, p. 143-155

Arleroth, J. & Kristensson, H. (2011). 'Waste in Lean Construction – A case study of a PEAB construction site and the development of a Lean Construction Tool'. Master's Thesis. Master of Supply Chain Management, Department of Technology Management and Economics, Division of Logistics and Transportation, Chalmers University of Technology, Gothenburg, Sweden

Armstrong, R.; Waters, E.; Jackson, N.; Oliver, S.; Popay, J.; Shepherd, J.; Petticrew, M.; Anderson, L.; Bailie, R.; Brunton, G.; Hawe, P.; Kristjansson, E.; Naccarella, L.; Norris, S.; Pienaar, E.; Roberts, H.; Rogers, W.; Sowden, A.; Thomas, H. (2007). 'Guidelines for Systematic reviews of health promotion and public health interventions'. Melbourne University, Australia. Link: http://ph.cochrane.org/sites/ph.cochrane.org/files/uploads/Guidelines%20HP_PH%20reviews.pdf

REFERENCES

AUMA (2012). 'Zero Waste Backgrounder - Transforming Municipalities from Waste Managers to Resource Managers'. Link:

http://www.auma.ca/live/digitalAssets/71/71992_Zero_Waste_Backgrounder-July_4th.pdf

Australian Bureau of Statistics (2010). '1350.0 - Australian Economic Indicators, Oct 2010'. Link:

<http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1350.0Feature+Article1Oct+2010>

AUT University (2015). 'AUT's Sustainability Goals 2012-2022'. Link:

<https://www.aut.ac.nz/about-aut/sustainability-at-aut/auts-commitment/?a=446603>

Ayarkwa, J.; Agyekum, K. & Adinyira, E. (2011). 'Exploring Waste Minimization Measures In The Ghanaian Construction Industry'. Built Environmental Journal Vol. 8, No. 2, p. 22-30

Babbie, E. (2007). 'The Practice of Social Research'. Wadsworth, Cengage Learning

Ball, P. D.; Evans, S.; Levers, A. and Ellison, D. (2009). 'Zero carbon manufacturing facility – towards integrating material, energy, and waste process flows'. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 223, p. 1085-1096

Ballard, G. (2008). 'Target Value Design'. Lean Construction Institute, University of California, Berkeley

Ballard, G. (2008). 'The Lean Project Delivery System: An Update'. Lean Construction Journal 2008, p. 1-19

REFERENCES

Banawi, A. A. (2013). 'Improving Construction Processes by Integrating Lean, Green, and Six-Sigma'. PhD Thesis: Swanson School of Engineering, University of Pittsburgh, USA

Barawas, M.; Fleetwood, C.; Folwell, K.; Garrett, R.; Hacche, I.; Liley, J.; Liston, S.; Scott, N. & Siddique, A. (2013). 'UK Construction: An economic analysis of the sector'. Department for Business Innovation & Skills

Barkley, D. L. (2006). 'The Value of Case Study Research On Rural Entrepreneurship: Useful Method?' Regional Economic Development Research Laboratory, E.D.A. University Center for Economic Development, Department of Applied Economics and Statistics, Clemson University, Clemson, South Carolina

Barman, B. and Nash, K. (2007). 'A Streamlined Real Options Model for Real Estate Development'. Unpublished Thesis: Master of Science in Real Estate Development, Department of Urban Studies and Planning, Massachusetts Institute of Technology

Baxter, P. & Jack, S. (2008). 'Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers'. *The Qualitative Report*, Vol, 13 No. p: 544-559

Beer, M.; Fridgen, G.; Mueller, H-V. & Wolf, T. (2013). 'Benefits Quantification in IT Projects'. 11th International Conference on Wirtschaftsinformatik, 27th February – 01st March 2013, Leipzig, Germany

Begum, R. A.; Swiwar, C.; Pereira, J. J. and Jaafar, A. H. (2006). 'A benefit-cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia'. *Resources, Conservation and Recycling* Vol. 48, p. 86–98

REFERENCES

- Begum, R. A.; Swiwar, C.; Pereira, J. J. and Jaafar, A. H. (2007). 'Factors and values of willingness to pay for improved construction waste management – A perspective of Malaysian contractors'. *Waste Management* Vol. 27, p. 1902–1909
- Begum, R. A.; Swiwar, C.; Pereira, J. J. and Jaafar, A. H. (2009). 'Attitude and behavioral factors in waste management in the construction industry of Malaysia'. *Resources, Conservation and Recycling* Vol. 53, p. 321–328
- Bentley, T. A.; Hide, S.; Tappin, D.; Moore, D.; Legg, S.; Ashby, L. & Parker, R. (2006). 'Investigating risk factors for slips, trips and falls in New Zealand residential construction using incident-centred and incident-independent methods', *Ergonomics*, Vol. 49, No. 1, p. 62-77, DOI: 10.1080/00140130612331392236
- Berry, C. (2014). 'Residential Construction Waste Reduction: Case Studies and Resources'. Report PUB/26 for Beacon Pathway Incorporated. Link: [http://www.beaconpathway.co.nz/images/uploads/Report_PUB\(26\)_Residential_Construction_Waste_Reduction_Case_Studies_v3.pdf](http://www.beaconpathway.co.nz/images/uploads/Report_PUB(26)_Residential_Construction_Waste_Reduction_Case_Studies_v3.pdf)
- Bin Yusoff, M. N. (2010). 'Waste Minimization by Recycling of Construction Waste'. Master's Thesis. Faculty of Civil Engineering & Earth Resources, University Malaysia Pahang, Malaysia
- Birge, J. R. (2012). 'Real-Options Valuation and Supply-Chain Management'. Lecture Notes, Northwestern University
- Black, M, Guy, M, McLellan, N (2003). 'Productivity in New Zealand 1998 to 2002'. New Zealand Treasury, Wellington 6008, New Zealand

REFERENCES

- Blais, V., et al. (2007). 'Using Real Options to Incorporate Price Risk in the Valuation of a Multi-Mineral Mine'. Book: 'Orebody modelling and strategic mine planning'; Editor: R. Dimitrakopoulos. Melbourne, AusIMM.
- Blanco, G. and F. Olsina (2011). 'Optimal Decision-Making under Uncertainty: Application to Power Transmission Investments'. Stochastic Optimization-Seeing the Optimal for the Uncertain. I. Dritsas, InTech.
- Boland, L. A. (2000). 'The Methodology of Economic Model Building'. Routledge
- Bon R. & Hutchinson K. (2000) 'Sustainable construction: some economic challenges'. Building Research & Information, Vol, 28, No. 5-6, p. 310-314
- Borison, A. (2003). 'Real Options Analysis: Where are the Emperor's Clothes?'. Real Options Conference. Washington DC, Stanford University.
- Borisov, D.; Stefanov, B. & Stoyanov, S. K. (2014). 'An Algorithm For Metallurgical Waste Minimization'. Journal of Chemical Technology and Metallurgy, Vol. 49, No. 1, p: 99-105
- Bossink, B. A. G. & Brouwers, H. J. H. (1996). 'Construction Waste: Quantification and Source Evaluation'. Journal of Construction Engineering and Management, p. 55-60
- Bourdeau, L. (2010). 'Sustainable development and the future of construction: a comparison of visions from various countries'. Building Research & Information, Vol. 27, No. 6, p. 354-366
- Boyle, C. (2004). 'Sustainable Buildings in New Zealand'. Discussion papers produced by the IPENZ Presidential Task Committee on Sustainability

REFERENCES

Boyle, C. (2010). 'Conditional simulation methods to determine optimum drill hole spacing'. Book: 'Advances in Orebody modelling and strategic mine planning 1'; Editor: R. Dimitrakopoulos, Melbourne, AusIMM.

BRANZ (2014). 'REBRI Tools'. Website. Link: http://www.branz.co.nz/cms_display.php?sn=111&. Access Date: March, 2014

Brettle, A. (2008). 'Systematic Reviews'. Article, School of Nursing and Midwifery, University of Salford. Link: <http://www.cprjournal.com/documents/systematicReviews.pdf>

Brochner J.; Ang, G. K. I. & Fredriksson, G. (1999). 'Sustainability and the performance concept: encouraging innovative environmental technology in construction'. Building Research & Information, Vol. 27, No. 6, p. 367-372

Brown, C. & Allcock, S. (2008). 'Waste Plasterboard Composting - Literature Review'. Envision New Zealand Limited in Preparation for the Ministry for the Environment

World Commission on Environment and Development (1987). Our Common Future. Oxford: Oxford University Press. p. 27. ISBN 019282080X.

Build It Green (2007). 'Home Remodeling: Green Building Guidelines'. Link: www.BuildItGreen.org

Building Performance (2015). 'The Importance of the Building and Housing Sector'. Link: <http://www.building.govt.nz/soi0710-parta2>

Burnett, J. (2007). 'City buildings—Eco-labels and shades of green!' Landscape and Urban Planning Vol. 83, p. 29–38

REFERENCES

Business Dictionary (2015). 'System Approach Definition'. Link:

<http://www.businessdictionary.com/definition/system-approach.html>

CABE (2006). 'Creating excellent buildings: A guide for clients'. Report/Guideline.

Caldwell, B. (1980). 'Positivist Philosophy of Science and the Methodology of Economics'. *Journal of Economic Issues*, Vol. XIV, No. 1, p. 54-76

Callagy, R. (2012). 'Option Theory and Land Development'. Lecture Notes, MIT Sloan School of Management

Card, P. (2009). 'Economic evaluation: it is time we cleaned-out or smartened-up our discipline'. Project Evaluation Conference, Melbourne, Vic.

Chang, Y-J & Lin, M-D. (2011). 'Economic Evaluation of Municipal Solid Waste Management System for Taiwan's Taichung Special Municipality'. 2nd International Conference on Environmental Science and Technology, Singapore

Chen J. J. & Chambers D. (1999). 'Sustainability and the impact of Chinese policy initiatives upon construction'. *Construction Management and Economics*, Vol. 17, No. 5, p. 679-687

Cheng, J. C. P. and Ma, L. Y. H. (2013). 'A BIM-based system for demolition and renovation waste estimation and planning'. *Waste Management* (in Review)

Chia, R. (2002). 'The Production of Management Knowledge: Philosophical Underpinnings of Research Design'. Book: 'Essential Skills for Management Research'. Editor: Partington, D.

REFERENCES

Chia, R. (2002). Book Section: 'The Production of Management Knowledge: Philosophical Underpinnings of Research Design'. Book: 'Essential Skills for Management Research'. Editor: Partington, D. Sage Publications

Chiara, N., Garvin, M. J. and Vecer, J. (2007). 'Valuing Simple Multiple-Exercise Real Options in Infrastructure Projects'. Journal of Infrastructure Systems Vol. 13, No. 2, p. 97-104

Chinda, T.; Pornpromptada, K.; Wadhanakul, N. & Chavengbenjaporn, S. (2012). 'Investigation of Factors Influencing Construction Waste Recycling Decisions'. Engineering, Project, and Production Management 2012 Conference

Chiu, RLH (2012). 'Sustainability'. University of Hong Kong, Hong Kong, China

Chong, W. K.; Kumar, S.; Haas, C. T.; Beheiry, S. M. A.; Coplen, L. & Oey, M. (2009). 'Understanding and Interpreting Baseline Perceptions of Sustainability in Construction among Civil Engineers in the United States'. Journal of Management in Engineering Vol. 25, p. 143-154

Chong, W.K; Kumar, S; Haas, C. T.; Beheiry, S. M. A.; Coplen, L.; and Oey, M. (2009). 'Understanding and Interpreting Baseline Perceptions of Sustainability in Construction among Civil Engineers in the United States'. Journal of Management in Engineering Vol. 25, No. 3, July 1, 2009, p.143-154

Christopher, M. and Peck, H. (2002). 'Building the Resilient Supply Chain'. Cranfield School of Management

REFERENCES

- Christou, E.; Anastasiadou, C. & Valachis, J. (2007). 'Research Methodology in Hospitality Industry: The role of the Inquiry Paradigms'. University of The Aegean, Mihalon 8, 82100, Chios, Greece
- Chung, S. S. & Lo, C. W.H. (2003). 'Evaluating sustainability in waste management: the case of construction and demolition, chemical and clinical wastes in Hong Kong'. *Resources, Conservation and Recycling* Vol. 37, p. 119-145
- Cleves Jr., J. A. & Michel, J. F. (2007). 'Lean project delivery: A winning strategy for construction and real estate development'. Grant Thornton
- Coates, P. & Kaushik, A. (2013). 'BIM Design and Pre-construction: New Models of Engagement - Using BIM, Target Value Design and Relational Contracts'. *Infra Projects*
- Cocchiarella, N. B. (2007). 'Formal Ontology and Conceptual Realism'. Springer
- Coelho, A. & de Brito, J. (2012). 'Influence of construction and demolition waste management on the environmental impact of buildings'. *Waste Management* Vol. 32, p. 532-541
- Cohen, L.; Manion, L. & Morrison, K. (2007). 'Research Methods in Education'. Routledge, Taylor & Francis
- Collier, A.; Cotterill, A.; Everett, T.; Muckle, R.; Pike, T. & Vanstone, A. (2010). 'Understanding and influencing behaviours: a review of social research, economics and policy making in Defra'. Department for Environment, Food and Rural Affairs, UK Government

REFERENCES

Collis, J. & Hussey, R. (2009) *Business Research: A practical guide for undergraduate and postgraduate students*, 3rd edition, New York, Palgrave Macmillan.

Conlin, R. (2012). 'Zero Waste in construction and demolition'. Website: Making It Work, Link: <http://conlin.seattle.gov/2012/12/20/zero-waste-in-construction-and-demolition/> (accessed 04 March 2013)

Connett, P. (2008). 'Zero Waste: A Key Move towards a Sustainable Society'. Link: <http://www.americanhealthstudies.org/zerowaste.pdf>

Construction Resources and Waste Platform (2010). 'The True Cost of Waste - Bricks'. Construction Resources and Waste Platform. Link: http://www.smartwaste.co.uk/filelibrary/True%20Cost%20of%20Waste/Brick_information_page.pdf

Coudert, L.; Blais, J-F.; Merciera, G.; Cooper, P.; Gastonguay, L.; Morris, P.; Janin, A. & Reynier, N. (2013). 'Pilot-scale investigation of the robustness and efficiency of a copper-based treated wood wastes recycling process'. *Journal of Hazardous Materials* Vol. 261, p. 277–285

Covec (2007). 'Recycling: Cost Benefit Analysis'. Report for the Ministry for the Environment (NZ)

Creswell, J. W & Clark, V. L. P. (2011). 'Designing and Conducting Mixed Methods Research'. Book. Sage Publishing

Cucchiella, F. and Gastaldi, M. (2006). 'Risk management in supply chain: A real option approach'. *Journal of Manufacturing Technology Management* Vol. 17, No. 6, p. 700-720

REFERENCES

- Curran, T. and Williams, I.D. (2012). 'A zero waste vision for industrial networks in Europe'. *Journal of Hazardous Materials* Vol. 207–208, p. 3–7
- Dainty, A. R. J. and Brooke, R. J. (2004). 'Towards improved construction waste minimisation: a need for improved supply chain integration?'. *Structural Survey* Vol. 22, No. 1, p. 20–29
- Dajadian, S. A. & Koch, D. C. (2014). 'Waste Management Models and Their Applications on Construction Sites'. *International Journal of Construction Engineering and Management* 2014, Vol. 3, No. 3, p. 91-98. Link: DOI: 10.5923/j.ijcem.20140303.02
- Dantus, M. M. & High, K. A. (1999). 'Evaluation of waste minimization alternatives under uncertainty: a multiobjective optimization approach'. *Computers and Chemical Engineering* Vol. 23, p: 1493 – 1508
- Davis, N (2007). 'Construction Sector Productivity-Scoping Report'. Martin-Jenkins, Wellington, New Zealand
- Davison, R. M. (1998). 'An Action Research Perspective of Group Support Systems: How to Improve Meetings in Hong Kong'. PhD Thesis, City University of Hong Kong. Link: <http://www.is.cityu.edu.hk/staff/isrobert/phd/phd.htm>
- De Vaus, D (2005) *Research design in Social Research*, New York University, New York, USA
- Denzin, N. K. & Lincoln, Y. S. (2005). 'The Sage Handbook of Qualitative Research (3rd ed.)'. Thousand Oaks, CA: Sage. ISBN 0-7619-2757-3

REFERENCES

Department for Environment, Food and Rural Affairs – Defra (2011). 'The Economics of Waste and Waste Policy'. Waste Economics Team, Environment and Growth Economics, Defra

Department of Environment Transport and the Regions (2000). 'Building a Better Quality of Life'. Report, HMSO, UK

Department of Housing and Building (2009). 'Report of the Building and Construction Sector Productivity Taskforce-A modern efficiency and productive New Zealand built infrastructure industry'. Department of Housing and Building, Wellington, New Zealand

Dharmavaram, S.; Mount, J. B. & Donahue, B. A. (1990). 'Automated Economic Analysis Model For Hazardous Waste Minimization'. Journal of the Air & Waste Management Association, Vol. 40, No. 7, p. 1004-1011

DiCicco-Bloom, B. & Crabtree, B. F. (2006). 'Making sense of qualitative research: The qualitative research interview'. Medical Education Vol. 40, p: 314–321, doi:10.1111/j.1365-2929.2006.02418.x

Dickson, J. & Lock, D. (2012). 'Construction Waste Prevention Strategy: Consideration of Waste Prevention in Materials Certification'. ZeroWIN. Link www.zeroWIN.eu

Dictionary (2015). 'Sustainability meaning'. Link: <http://dictionary.reference.com/browse/sustainability>

Dimitrakopoulos, R. (2010). 'Stochastic mine planning: methods, examples and value in an uncertain world'. Book: 'Advances in Orebody modelling and strategic mine planning', Editor: R. Dimitrakopoulos, AusIMM Conference, Melbourne

REFERENCES

- Dimitrakopoulos, R. and Sabour, S. (2007). 'Evaluation mine plans under uncertainty: Can real options make a difference?'. *Resources Policy* Vol. 32, p. 1-10
- Dimitrakopoulos, R., Martinez, L. and Ramazan, S. (2007). 'A maximum upside/minimum downside approach to the traditional optimization of open pit mine design'. *Journal of Mining Science* Vol. 43, No. 1, p. 73-82
- Ding, G. K. C (2007). 'Sustainable construction - The role of environmental assessment tools'. *Journal of Environmental Management* Vol. 86, p. 451–464
- Dolan, P. J; Lampo, R. G. & Dearborn, J. C. (1999). 'Concepts for Reuse and Recycling of Construction and Demolition Waste'. US Army Corps of Engineers - Construction Engineering Research Laboratories
- Doppelt, B.; Dowling-Wu, L. and Seldman, N. (1999). 'Report for Oregon and the Pacific Northwest: Establishing Environmentally Sustainable and Economically Efficient Economies: From Waste Management towards Zero Waste'
- Dowd, K. (2005). 'Measuring market risk'. Book, John Wiley & Sons, Chichester, England
- Drummond, M. & Sculpher, M. F(2005). 'Common Methodological Flaws in Economic Evaluations'. *Medical Care*, Vol. 43, No. 7
- du Plessis, C. (2001). 'Sustainability and sustainable construction: the African context'. *Building Research & Information*, Vol. 29, No. 5, p. 374-380
- Dunn, K. (2010). Book Section: 'Interviewing'. Book: 'Qualitative Research Methods in Human Geography'. Editor: Hay, I.

REFERENCES

Easterby-Smith, M; Thorpe, R. & Lowe, A. (2002). 'Management Research: An Introduction'. Sage Publishing

Ecolife (2015). 'Definition of Waste Management'. Link: <http://www.ecolife.com/define/waste-management.html>

Edum-Fotwe, F. T. & Price, A. D. F. (2009). 'A social ontology for appraising sustainability of construction projects and developments'. International Journal of Project Management Vol. 27, p. 313–322

Egan, J. (1998). 'Rethinking Construction - The report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction'.

Environment Protection Authority (EPA) (2009). 'Waste definitions'. Waste Guide. South Australia Government

Environmental New South Wales, (2014). 'Sustainability Advantage'. Link: <http://www.environment.nsw.gov.au/sustainbus/sustainabilityadvantage.htm>. Access date: 28/05/2014 and 28/05/2015

Environmental Protection Agency (2002). 'What Is Integrated Solid Waste Management?'. Fact Sheet, USA

Environmental Protection Agency (2009). 'EPA Guideline: Waste Definitions'. Link: www.epa.sa.gov.au/files/4771336_guide_waste_definitions.pdf. Access Date 26/05/2015

EPPI (2010). 'EPPI-Centre Methods for Conducting Systematic Reviews'. Report, Social Science Research Unit, Institute of Education, University of London. Link: <http://eppi.ioe.ac.uk/cms/LinkClick.aspx?fileticket=hQB8y4uVwI%3D&tabid=88>

REFERENCES

Fadiya, O. O.; Georakis, P. & Chinyio, E. (2014). 'Quantitative Analysis of the Sources of Construction Waste'. *Journal of Construction Engineering*, Volume 2014. Link: <http://dx.doi.org/10.1155/2014/651060>

Farrow, J. R. (2011). 'Risk Identification and the Quantification of Sustainability Comprehensive Financial Cost Benefit Analysis that Includes Environmental and Social Costs - 11553'. *Waste Management 2011 Conference*, February 27 – March 3, 2011, Phoenix, AZ, USA

Fatta, D.; Papadopoulos, A.; Avramikos, E.; Sgourou, E.; Moustakas, K.; Kourmoussis, F.; Mentzis, A.; Loizidou, M. (2003). 'Generation and management of construction and demolition waste in Greece—an existing challenge'. *Resources, Conservation and Recycling* Vol. 40, p. 81-91

Fayad, R.; Bekhazi, C.; Ford, R.; Chikhail, M.; Demashkieh, M.; Kahwaji, R.; Sulaiman, A.; Sakar, M; Othmani, A. & Marrouf, M. (2009). 'Environmental and Social Impact Assessment of Construction and Operation of Syria Cement Plant and Captive Power Plant and Associated Quarry Operations, Syria'. ELARD SYRIA & GOLDBER ASSOCIATES AFRICA

Feast, L. & Melles (2010). 'Epistemological Positions in Design Research: A Brief Review of the Literature'. *Connected 2010 –2nd International Conference On Design Education* 28 June -1 July 2010, University of New South Wales, Sydney, Australia

Fellows, R. & Liu, A. (2007). 'Impacts of Participants' Values on Sustainability of Construction Projects'. *School of the Built and Natural Environment, Glasgow Caledonian University and Department of Real Estate and Construction, The University of Hong Kong*.

REFERENCES

Fernández-Sánchez, G. & Rodríguez-López, F. (2010). 'A methodology to identify sustainability indicators in construction project management - Application to infrastructure projects in Spain'. *Ecological Indicators* Vol. 10, p. 1193–1201

Ford, D., Lander, D. and Voy, J. J. (2002). 'A real options approach to valuing strategic flexibility in uncertain construction projects'. *Construction Management and Economics* Vol. 20, p. 343-351

Foster, J.; Lowe, A.; Winkelman, S. (2011). 'The Value of Green Infrastructure for Urban Climate Adaptation'. Center for Clean Air Policy

Fox, R. (2008). 'A brief critical history of NPV'. Salford University

Fredricsen, P. (2003). 'The Changing Scene for Construction and Demolition Waste Recycling'. Materials Processing Ltd. Link:

<http://www.ioqnz.co.nz/uploads/The%20Changing%20Scene%20for%20Construction%20and%20Demolition%20Waste%20Rec.pdf>

Funk, K.; Milford, J. & Simpkins, T. (2013). 'Waste Not, Want Not: Analyzing the Economic and Environmental Viability of Waste-to-Energy (WTE) Technology for Site-Specific Optimization of Renewable Energy Options'. National Renewable Energy Laboratory for The Joint Institute for Strategic Energy Analysis, U.S. Department of Energy

Gamba, A. and Fusari, N. (2009). 'Valuing modularity as a real option'. *Management Science* Vol. 55, No. 11, p. 1877-1896

REFERENCES

Gay, A. E.; Beam, T. G. & Mar, B. W. (1993). 'Cost-effective solid-waste characterization methodology'. *Journal of Environmental Engineering*, Vol. 119, No. 4, p. 631-644

General Motors (2012). 'The Business Case for Zero Waste'. GM News, Link: http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2012/Oct/1019_Landfill-FreeBlueprint.html

Gibbs, A. (1997). 'Focus Group'. Link: <http://sru.soc.surrey.ac.uk/SRU19.html>

Gill, S.E. Handley, J.F. Ennos, A.R. & Pauleit, S. (2006). 'Adapting Cities for Climate Change: The Role of the Green Infrastructure'. *Built Environment* Vol. 33 No. 1, p. 115-133

Glavic, P. & Lukman, R. (2006). 'Review of sustainability terms and their definitions'. *Journal of Cleaner Production* Vol. 15, p. 1875-1885

Goldman, G. & Ogishi, A. (2001). 'The Economic Impact Of Waste Disposal And Diversion In California'. A Report To The California Integrated Waste Management Board. Department of Agricultural and Resource Economics, University of California, Berkeley

Gordon, D. (2013). 'Interviewing in Qualitative Research'. Universal Design Research Group, Room K107A, School of Computing, Dublin Institute of Technology, Kevin Street, Dublin 8

Graham, T. & Mitchell, L. (2011). 'Recycling construction waste'. *Build Magazine*, BRANZ

REFERENCES

- Grant, A., et al. (2005). 'Mining and commodities exports'. The Australian Treasury
Canberra
- Grasselli, M. R. (2003). 'Getting real with Real Options'. Management Science
- Gray, D. E. (2004). 'Doing Research in the Real World'. Sage Publishing
- Gray, D. E. (2009). 'Doing Research in the Real World – 2nd Edition'. Sage Publishing
- Green Building Solutions (2013). 'What is Green Construction?'. Webs address:
<http://www.greenbuildingsolutions.org/Main-Menu/What-is-Green-Construction>. Access
date: 04/08/2013
- Green Star NZ (2009). 'Interior Assessment Guide'. New Zealand Green Building
Council.
- Green, S. & May, S. (2003). 'Re-engineering construction: going against the grain'.
Building Research & Information, Vol. 31, No. 2, p. 97-106
- Greenwood, D. J. (2001). 'Subcontract procurement: Are relationships changing?'.
Construction Management and Economics Vol. 19, p. 5-7
- Greeves, J. T., Stoll, R. and Tauxe, J. (2010). 'Risk-Based Performance Assessment of
Large Projects'. WM2010 Conference, Phoenix, AZ
- Gruber, T. R. (1995). 'Toward principles for the design of ontologies used for knowledge
sharing'. International Journal of Human-Computer Studies, Vol. 43, Issues 4-5,
November 1995, pp. 907-928
- Guma, A. C. (2008). 'A Real Options Analysis of a Vertically Expandable Real Estate
Development'. Unpublished Thesis: Master of Science in Real Estate Development,
Department of Urban Studies and Planning, Massachusetts Institute of Technology

REFERENCES

- Gurtler-Schrieverhoff, M. P.; Engel, A.; Lindermann, U. & Yosefzon, Y. (2014). 'DFA Methodology Guide and Economic Model'. European Union - Research, Technological Development & Demonstration (RTD), Seventh Framework Programme (FP7), Rue Montoyer 75, MO75 - 2/4 - 1049 Brussels
- Guy, G. B. & Kibert, C. J. (1998). 'Developing indicators of sustainability: US experience'. *Building Research & Information*, Vol. 26, No. 1, p. 39-45
- Haapio, A. & Viitaniemi, P. (2008). 'A critical review of building environmental assessment tools'. *Environmental Impact Assessment Review* Vol. 28, p. 469–482
- Hadjieva-Zaharievaa, R.; Dimitrova, E. & Buyle-Bodin, F. (2003). 'Building waste management in Bulgaria: challenges and opportunities'. *Waste Management* Vol. 23, p. 749–761
- Haik, Y. & Shahin, T. (2011). 'Engineering Design Process – Second Edition'. Cengage Learning, 200 First Stamford Place, Suite 400, Stamford, CT 06902, USA
- Hajdasinski, M. M. (2012). 'The payback period as a measure of profitability and liquidity'. Link: <http://www.allbusiness.com/accounting-reporting/record-keeping/391065-1.html#ixzz1jszarXFx>
- Hall, J. and Nicholls, S. (2006). 'Valuation of mining projects using option pricing techniques'. CPA Australian Mining and Energy Conference, UQ Business School, The University of Queensland
- Hall, M. & Purchase, D. (2006). 'Building or Bodging? Attitudes to Sustainability in UK Public Sector Housing Construction Development'. *Sustainable Development* Vol. 14, p. 205–218

REFERENCES

- Hamzed, F. & Bergstrom, E. (2010). 'The Lean Transformation: A Framework for Successful Implementation of the Last Planner System in Construction'. Colorado State University, Fort Collins, Colorado
- Hao, J. L.; Hills, M. J. and Huang, T. (2007). 'A simulation model using system dynamic method for construction and demolition waste management in Hong Kong'. *Construction Innovation* Vol. 7, No. 1, p. 7-21
- Hartlen, J. (1996). 'Environmental Consequences of Using Residues'. *Waste Management* Vol. 16, No. 1 -3, p. 1-6.
- Hassan, S. H.; Ahzahar, N.; Fauzi, M. A. & Eman, J. (2012). 'Waste Management Issues in the Northern Region of Malaysia'. *Procedia - Social and Behavioral Sciences* Vol. 42 p. 175-181
- Hatmoko, J. and Scott, S. (2010). 'Simulating the impact of supply chain management practice on the performance of medium-sized building projects'. *Construction Management and Economics* Vol. 28, No. 15, p. 35-49
- Henderson, V. and D. G. Hobson (2001). 'Real options with constant relative risk aversion'. *Journal of Economic Dynamics & Control* Vol. 27
- Hendler, S. (1980). 'Planning Issues and Sustainable Development'. *Planning, Theory, Practice and Education*. Center for Urban Policy Research, New Brunswick, NJ, pp. 104–19
- Hengels, A. (2005). 'Creating a Practical Model Using Real Options to Evaluate Large-Scale Real Estate Development Projects'. Unpublished Thesis: Master of Science in

REFERENCES

Real Estate Development, Department of Architecture, Massachusetts Institute of Technology

HERA (2010). 'IMPORTED STEELWORK: Economic Social and Risk-related Impacts'. HERA Report No R5-40

Hiles, D. (2001). 'Heuristic Inquiry and Transpersonal Research'. Conference: CCPE, London - October, 2001. Link: <http://www.psy.dmu.ac.uk/drhiles/HIpaper.htm>

Hill R. C. & Bowen P. A. (1997). 'Sustainable construction: principles and a framework for attainment'. Construction Management and Economics, Vol, 15, No. 3, p. 223-239

Hoare (2007). 'Role of Simulation Modelling in Project Evaluation'. Project Evaluation Conference, Melbourne, Australian Institute of Mining and Metallurgy

Hogland, W. and Marques, M. (2007). 'Sustainable Waste Management: International Perspectives'. Proceedings of the International Conference on Sustainable Solid Waste Management, 5 - 7 September 2007, Chennai, India. pp.1-8

Holden, M. T. & Lynch, P. (1999). 'Choosing the Appropriate Methodology: Understanding Research Philosophy'. Waterford Institute of Technology, Cork Road, Waterford

Holton, I; Glass, J. & Price, A. (2008). 'Developing a Successful Sector Sustainability Strategy: Six Lessons from the UK Construction Products Industry'. Corporate Social Responsibility and Environmental Management Vol. 15, p.29-42

Hopkins. W. G. (2000). 'Quantitative Research Design'. Department of Physiology, University of Otago, Dunedin 9001, New Zealand

REFERENCES

- Hostetlera, M.; Allen, W. & Meurk, C. (2011). 'Conserving urban biodiversity? Creating green infrastructure is only the first step'. *Landscape and Urban Planning* Vol. 100, p. 369–371
- Howell, G. A. (1999). 'What Is Lean Construction – 1999'. *Proceedings IGLC-7*. Link: <http://www.lcinm.org/uploads/Howell.pdf>
- Howell, G. A. (2001). 'Lean Project Delivery'. *Lean Construction Institute*
- Hu, Y. (2011). 'Minimization Management of Construction Waste'. Department of Construction Engineering Management, Henan University of Urban Construction, Ping Dingshan, China
- Huang, W-L.; Lin, D-H.; Chang, N-B. and Lin, K-S. (2002). 'Recycling of construction and demolition waste via a mechanical sorting process'. *Resources, Conservation and Recycling* Vol. 37, p. 23-37
- Hueting, R. & Reijnders, L. (2004). 'Broad sustainability contra sustainability: the proper construction of sustainability indicators'. *Ecological Economics* Vol. 50, p. 249–260
- Hughes, J. A. & Sharrock, W. W. (1997). 'The Philosophy of Social Research'. Longman Publishing
- Huglin, L. M. (2003). 'The relationship between personal epistemology and learning style in adult learners'. *Dissertation Abstracts International*, Vol. 64, No. 03, p: 759
- Hult, G., Craighead, C. W. and Ketchen, D. J. (2010). 'Risk uncertainty and supply chain decisions: A real options perspective'. *Decision Sciences Journal* Vol. 4, No. 3, p. 435-458

REFERENCES

- Hyder Consulting; Encycle Consulting & Sustainable Resource Solutions (2011). 'Construction and Demolition Waste Status Report - Management of Construction And Demolition Waste In Australia'. Hyder Consulting Pty Ltd
- IAEA (1999). 'Review of the factors affecting the selection and implementation of waste management technologies'. Waste Technology Section, International Atomic Energy Agency, Wagramer Strasse 5, P.O. Box 100, A-1400 Vienna, Austria
- Jacoby, H. D. and D. G. Laughton (1991). 'Project Evaluation: A Practical Asset Pricing Method'. Massachusetts Institute of Technology, Cambridge, MA, USA
- Jaillon, L.; Poon, C. S. and Chiang, Y. H. (2009). 'Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong'. Waste Management Vol. 29, p. 309-320
- Jain, M. (2012). 'Economic Aspects of Construction Waste Materials in terms of cost savings – A case of Indian construction Industry'. International Journal of Scientific and Research Publications, Volume 2, Issue 10
- Jansen, K. J.; Corley, K. G. & Jansen, B. J. (2007). 'E-Survey Methodology'. Book: 'Handbook of Research on Electronic Surveys and Measurements'. Editors: Reynolds, R. A.; Woods, R. & Baker, J. D.
- Janssen. J, McLoughlin. S (2008). 'New Zealand"s Productivity Performance'. New Zealand Treasury, Wellington 6015, New Zealand
- Jaques, R. (1988). 'The Influence of Design and Procurement on Construction Site Waste Generation -A Pilot Study'. BRANZ Report No. 81 (1998)

REFERENCES

- Jaques, R. (1998). 'The Influence of Design and Procurement on Construction Site Waste Generation -A Pilot Study'. BRANZ Report No. 81 (1998)
- Jensen, M. C and Smith, C. W. (1984). 'The Theory of Corporate Finance: A Historical Overview'. Book: 'The Modern Theory of Corporate Finance', Editor: Michael C. Jensen and Clifford W. Smith, Jr. (New York: McGraw-Hill Inc., 1984) pp. 2- 20
- Jin, J.; Wang, Z. & Ran, S. (2006). 'Solid waste management in Macao: Practices and challenges'. Waste Management Vol. 26, p. 1045-1051
- Jones, H. & Jones, P. (2007). 'Cities and sustainability'. Landscape and Urban Planning Vol. 83, p. 1
- Jonker, J. & Pennink, B. W. (2010). 'The Essence of Research Methodology: A Concise Guide for Master and PhD Students in Management Science'. Springer, Heidelberg
- Kaare, K. and Koppel, O. (2012). 'Improving the road construction supply chain by developing a national level performance measurement system: The case of Estonia'. International Journal of Social and Human Sciences Vol. 6, p. 225-231
- Kaboub, F. (2008). 'Positivist Paradigm'. Encyclopedia-Vol -2 (Pat 2). Page 343
- Kale, S. and Arditi, D. (2001). 'General Contractor's relationships with subcontractors: A strategic asset'. Construction Management and Economics Vol.19, p. 541-549
- Kambites, C. & Owen, S. (2006). 'Renewed prospects for green infrastructure planning in the UK'. Planning Practice & Research, Vol. 21, No. 4, p. 483-496
- Kara, S., Kayis, B. and Gomez, E. (2008). 'Managing supply chain risks in multi-site, multi-partner engineering projects'. Journal Paper, IBIMA Vol. 5, p. 100-112

REFERENCES

- Kara, S., Kayis, B. and Gomez, E. (2008). 'Managing supply chain risks in multi-site, multi-partner engineering projects'. Journal Paper, IBIMA Vol. 5, p. 100-112
- Kazor, M. and Koppel, J. (2007). 'Scoping Waste in the Residential Built Environment: Final Report'. Beacon Pathway Ltd, Auckland
- Kartam, N.; Al-Mutairi, N.; Al-Ghusain, I. and Al-Humoud, J. (2004). 'Environmental management of construction and demolition waste in Kuwait'. Waste Management Vol. 24, p. 1049–1059
- Kats, G. H. (2003). 'Green Building Costs and Financial Benefits'. Massachusetts Technology Collaborative
- Kazor, M. and Koppel, J. (2007). 'Scoping Waste in the Residential Built Environment: Final Report'. Beacon Pathway Ltd, Auckland
- Keegan, G. (2014). 'The Experimental Method'. Link: <http://www.gerardkeegan.co.uk/resource/experimentalmeth1.htm>
- Keivan, S. (2013). 'Waste management at no extra cost'. Unpublished Master's Dissertation. For the Degree of Masters in Engineering Project Management, Engineering Project Management Programme, School of Engineering, AUT.
- Kestle, L. and Rimmer, T. (2010). 'Sustainable design and construction education - getting students on board with the real challenges in NZ'. Report Number SB10NZ, UNITEC Institute of Technology, Faculty of Technology and Built Environment, PB 92-025, Auckland, New Zealand
- Khalfan, M. M. A. (2006). 'Managing sustainability within construction projects'. Journal of Environmental Assessment Policy and Management Vol. 8, No. 1 pp. 41–60

REFERENCES

- Khanzode, A; Fischer, M.; Reed, D. & Ballard, G. (2006). 'A Guide to Applying the Principles of Virtual Design & Construction (VDC) to the Lean Project Delivery Process'. CIFE Working Paper #093, Center For Integrated Facility Engineering
- Kijjanapanich, P.; Annachhatre, A. P.; Esposito, G.; van Hullebusch, E. D. & Lens, P. N. L. (2013). 'Biological sulfate removal from gypsum contaminated construction and demolition debris'. *Journal of Environmental Management* Vol. 131, p. 82-91
- Kim, K. (2003). 'Real Options: A Way to Deal With Market Uncertainty in Real Estate Development Projects'. Unpublished Thesis: Master of Science in Real Estate Development, Department of Architecture, Massachusetts Institute of Technology
- Kinuthia, J.M. and Nidzam, R.M. (2011). 'Towards zero industrial waste: Utilisation of brick dust waste in sustainable construction'. *Waste Management*, Vol. 31, p. 1867–1878
- Knight (2007). 'Is Zero Waste Conceivable?'. Zero Waste NZ Report
- Kofoworola, O. F. and Gheewala, S. H. (2009). 'Estimation of construction waste generation and management in Thailand'. *Waste Management* Vol. 29, p. 731-738
- Konstantinou, T. & Knaack, U. (2012). 'An Integrated Refurbishment Design Process to Energy Efficiency'. Faculty of Architecture, Department of AE+T, Delft University of Technology Julianalaan 134, 2628 BL, Delft, the Netherlands
- Koskela, L. (1992). 'Application of the New Production Philosophy to Construction'. Technical Report # 72. Center for Integrated Facility Engineering. Department of Civil Engineering. Stanford University, pp75

REFERENCES

- Kothari, C. R. (2004). 'Research Methodology: Methods and Techniques'. Second Edition. New Age International Ltd Publishers
- Kourmpanis, B.; Papadopoulos, A.; Moustakas, K.; Stylianou, M.; Haralambous, K. J. and Loizidou, M. (2008). 'Preliminary study for the management of construction and demolition waste'. *Waste Management & Research* Vol. 26, p. 267–275
- Kubba, S. (2009). 'LEED Practices, Certification, and Accreditation Handbook, 1st Edition'. Publisher: Butterworth-Heinemann
- Kubba, S. (2011). 'Green Construction Project Management and Cost Oversight'. Publisher: Architectural Press
- Kucukvar, M.; Egilmez, G. & Tatari, O. (2016). 'Life Cycle Assessment and Optimization-Based Decision Analysis of Construction Waste Recycling for a LEED-Certified University Building'. *Sustainability* 2016, Vol. 8, No. 89; doi:10.3390/su8010089
- Kulatunga, U.; Amaratunga, D.; Haigh, R. and Rameezdeen, R. (2006). 'Attitudes and perceptions of construction workforce on construction waste in Sri Lanka'. *Management of Environmental Quality: An International Journal* Vol. 17, No. 1, p. 57-72
- Kumar, V.; Bee, D. J.; Shirodkar, P. S.; Tumkor, S.; Bettig, B. P. and Sutherland, J. W. (2005). 'Towards Sustainable "Product and Material Flow" Cycles: Identifying Barriers to Achieving Product Multi-Use and Zero Waste'. 2005 ASME International Mechanical Engineering Congress and Exposition November 5-11, 2005, Orlando, Florida USA
- Kumara, T. D. W. (2009). 'Construction & Demolition Waste Management Practices of Building Projects In Sri Lanka'. Dissertation for Master of Business Administration,

REFERENCES

Department of Management of Technology, University of Moratuwa, Sri Lanka. Link: <http://dl.lib.mrt.ac.lk/bitstream/handle/123/1266/94840.pdf?sequence=1>

Kuslyaykina, D. (2013). 'Exploratory Study of Waste Generation and Waste Minimization in Sweden'. Master's Thesis, Department of Earth Sciences, Uppsala University

Lai, F. J. and W. Stange (2009). 'Using Value-at-Risk for integrated project risk evaluation'. Project Evaluation Conference, Melbourne, Vic

Lam, P. T.I.; Chan, E. H.W.; Poon, C.S.; Chau, C.K. & Chun, K.P. (2010). 'Factors affecting the implementation of green specifications in construction'. Journal of Environmental Management Vol. 91, p. 654–661

Landauer, J. & Rowlands, J. (2001). 'Importance of Philosophy'. Link: <http://www.importanceofphilosophy.com/FiveBranchesMain.html>

Landin, A. and Öberg, M. (2014) Productivity and Efficiency in the Development of the Swedish Construction Sector. American Journal of Industrial and Business Management, 4, 307-318. Link: www.scirp.org/journal/PaperDownload.aspx?paperID=47367

Langfield, N. (2011). 'Building up Zero Waste'. Link: http://www.resource.uk.com/article/Comment/Building_zero_waste#.UTQk1zBkOSo (accessed 04 March 2013)

Laurie, A. (2016). 'Log Pricing Tables'. Laurie Forestry Ltd. Link: <http://www.laurieforestry.co.nz/Pricing-Table>

REFERENCES

Lawson, R. (2013). 'The importance of construction sector to the overall economy'. Wales Business. Link: <http://www.walesbusiness.org/2013/08/the-importance-of-construction-sector-to-the-overall-economy/>

Lee, E. G. and D. M. Strang. (2003a). 'Valuation techniques used in the mining industry Part one: Cost, market and income approaches'. Link: <http://www.allbusiness.com/mining-extraction/mines-mining/16431294-1.html#ixzz1b0aWZ5No>. Retrieved 20 October, 2013,

Lee, E. G. and D. M. Strang. (2003b). 'Valuation techniques used in the mining industry part two: Sensitivity analysis measures risk'. Link: <http://www.allbusiness.com/science-technology/computer-science-computational-research/16555364-1.html#ixzz1b0bXoH2r>. Retrieved 20 October, 2013,

Lee, E. G. and D. M. Strang. (2003c). 'Valuation techniques used in the mining industry Part three: Real option valuation approach'. Link: <http://www.allbusiness.com/mining-extraction/mines-mining-metal-ore-gold/16406278-20131.html#ixzz1b0bwjbAw>. Retrieved 20 October,

Lehmann, S. (2011). 'Optimizing Urban Material Flows and Waste Streams in Urban Development through Principles of Zero Waste and Sustainable Consumption'. Sustainability 2011, Vol. 3, p. 155-183

Lehmann, S. (2011). 'Resource Recovery and Materials Flow in the City: Zero Waste and Sustainable Consumption as Paradigms in Urban Development. Sustainable Development Law & Policy, Vol. 11, Iss. 1, p. 28-38

LePatner, B. B. (2008). 'The Industry That Time Forgot: What's wrong with the \$1 trillion construction business?'. Link: <http://www.itif.org/files/LePatnerPresentation.pdf>

REFERENCES

- Letendre, E. (2013). Planning for the Effective Reuse of Products in the New Zealand Building Industry - A Dunedin Case Study (Thesis, Master of Planning). University of Otago. Retrieved from <http://hdl.handle.net/10523/3661>
- Level (2015). 'Minimising waste'. Website. Link: <http://www.level.org.nz/material-use/minimising-waste/> Access Date: May, 2015
- Levin, H. (2000). 'Design and Construction of Healthy and Sustainable Buildings'. Building Ecology Research Group, 2548 Empire Grade, Santa Cruz, CA, 95060 USA
- Li, H.; Chen, Z.; Yng, L. and Kong, S. C.W. (2005). 'Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency'. Automation in Construction Vol. 14, p. 323–331
- Li, J.; Ding, Z.; Mi, X & Wang, J. (2013). 'A model for estimating construction waste generation index for building project in China'. Resources, Conservation and Recycling Vol. 7, p. 20–26
- Lingard, H.; Gilbert, G. and Graham, P. (2001). 'Improving solid waste reduction and recycling performance using goal setting and feedback'. Construction Management and Economics, Vol. 19, No. 8, p. 809-817
- Lingard, H.; Graham, P. and Smithers, G. (2000). 'Employee perceptions of the solid waste management system operating in a large Australian contracting organization: implications for company policy implementation'. Construction Management and Economics Vol. 18, No. 4, p. 383-393
- Liss, G. (2000). 'Local government incentives for Zero Waste'. Link: http://archive.grrn.org/zerowaste/articles/loc_gov_zw_incentives.html

REFERENCES

- Llatas, C. (2011). 'A model for quantifying construction waste in projects according to the European waste list'. *Waste Management* Vol. 31, p. 1261–1276
- Lorenz, D. P.; Truck, S. & Lutzkendorf, T. (2007). 'Exploring the relationship between the sustainability of construction and market value: Theoretical basics and initial empirical results from the residential property sector'. *Property Management* Vol. 25 No. 2, p. 119-149
- Love, P. E. D.; Holt, G. D; Shen, L. Y. and Irani, Z. (2002). 'Using systems dynamics to better understand change and rework in construction project management systems'. *International Journal of Project Management* Vol. 20, p. 425–436
- Lu, W & Yuan H. (2011). 'A framework for understanding waste management studies in construction'. *Waste Management* Vol. 31, p. 1252–1260
- Lu, W. and Yuan, H. (2010). 'Exploring critical success factors for waste management in construction projects of China'. *Resources, Conservation and Recycling* Vol. 55, p. 201–208
- Lu, W; Yuan H.; Li, J.; Hao, J. J. L.; Mi, X & Ding, Z. (2011). 'An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China'. *Waste Management* Vol. 31, p. 680–687
- M'ikiugu, M. M.; Kinoshita, I. & Tashiro, Y. (2012). 'Urban Green Space Analysis and Identification of its Potential Expansion Areas'. *Procedia - Social and Behavioral Sciences* Vol. 35 p. 449 – 458

REFERENCES

- M'ikiugu, M. M.; Wang, Q-N. & Kinoshita, I. (2012). 'Green Infrastructure Gauge: A tool for evaluating green infrastructure inclusion in existing and future urban areas'. *Procedia - Social and Behavioral Sciences* Vol. 68 p. 815 – 825
- MacDonald, G. (2003). 'Using systematic reviews to improve social care'. SCIE Reports: No 4. Link: <http://www.scie.org.uk/publications/reports/report04.pdf>
- Mackenzie, W. and N. Cusworth (2006). 'The Use and Abuse of Feasibility Studies'. Project Evaluation Conference Melbourne, Vic
- Macmillan, F. (2000). 'Risk, Uncertainty and Investment Decision-Making in the Upstream Oil and Gas Industry'. Ph. D. Thesis, University of Aberdeen, Aberdeen
- Macomber, H. & Barberio, J. (2007). 'Target-Value Design: Nine Foundational Practices for Delivering Surprising Client Value'. Lean Project Consulting, Inc.
- Manowong, E. (2012). 'Investigating factors influencing construction waste management efforts in developing countries: an experience from Thailand'. *Waste Management & Research*, Vol. 30, No. 1, p: 56-71
- Manzini, F.; Islas, J. & Macías, P. (2011). 'Model for evaluating the environmental sustainability of energy projects'. *Technological Forecasting & Social Change* Vol. 78, p. 931–944
- Maria, A. (1997). 'Introduction to Modelling and Simulation'. The 1997 Winter Simulation Conference, Atlanta, GA, USA
- Marshall, C. & Rossman, G. B. (2011). 'Designing Qualitative Research 5th Edition'. Sage Publishing

REFERENCES

- Marshall, R. E. & Farahbakhsh, K. (2013). 'Systems approaches to integrated solid waste management in developing countries'. *Waste Management*, Vol. 33, p. 988–1003
- Martinez, L. (2009). 'Why accounting for uncertainty and risk can improve final decision-making in strategic open pit mine design'. *Project Evaluation Conference*, Melbourne, Victoria
- Marzouk, M. & Azab, S. (2014). 'Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics'. *Resources, Conservation and Recycling* Vol. 82, p. 41– 49
- Mason, I.G.; Brooking, A.K.; Oberender, A.; Harford, J.M. and Horsley, P.G. (2003). 'Implementation of a zero waste program at a university campus'. *Resources, Conservation and Recycling*, Vol. 38, p. 257-269
- Maybee, B. M. (2010). 'A Risk-based Evaluation Methodology for Underground Mine Planning'. PhD Thesis, School of Graduate Studies Sudbury, Laurentian University
- Maybee, B., et al. (2010). 'Risk-based decision making within strategic mine planning'. *International Journal of Mining and Mineral Engineering* Vol. 2, No. 1
- McDonagh, M.; Whiting, P.; Bradley, M.; Cooper, J.; Sutton, A.; Chestnutt, I.; Misso, K.; Wilson, P.; Treasure, E. and Kleijnen, J. (2007). 'A Systematic Review of Public Water Fluoridation'. NHS Centre for Reviews and Dissemination, University of York. Link: <http://www.nhs.uk/Conditions/Fluoride/Documents/crdreport18.pdf>
- McDonald, B. & Smithers, M. (1998). 'Implementing a waste management plan during the construction phase of a project: a case study'. *Construction Management and Economics* Vol. 16, No. 1, p. 71-78

REFERENCES

McGrath, C. (2001). 'Waste minimisation in practice'. Resources, Conservation and Recycling Vol. 32, p. 227 – 238

McKernon, S; Bates, S.; Stoecklein, A.; Maplesden, F. & Bayne, K. (2004). 'Influencing People's Uptake of Sustainability in Housing (CON 1)'. Forest Research

Med ZeroWaste (2011). 'Zero Waste Systems' Analysis: Common Report'. Link: <http://www.med-zerowaste.eu/deliverables/Zero%20Waste%20Systems%20Analysis%20Common%20Report.pdf>

Mell, I. C. (2008). 'Green Infrastructure: concepts and planning'. FORUM Ejournal ol. 8, p. 69-80

MetalCorp (2016). 'Scrap Metal Price - Price List'. Link: <http://www.metalcorp.co.nz/pricelist.php>

Metro Vancouver (2011). 'Zero Waste challenge: Accelerating construction and demolition waste diversion'. Link: <http://www.metrovancouver.org/region/dialogues/Reports%20and%20Issue%20Summary%20Notes/Constuction-DemolitionWaste-CNE-Summary20110517.pdf> (accessed 04 March 2013)

MfE - Ministry for the Environment (2008). 'Recycling: Cost Benefit Analysis'. Link: <http://www.mfe.govt.nz/publications/waste/recycling-cost-benefit-analysis/5-markets-and-value-materials>

Michigan State University (2013). 'Taiwan Economy'. Link: <http://globaledge.msu.edu/countries/taiwan/economy>. Access date 10/09/2013

REFERENCES

Ministry for the Environment (1997). 'National Waste Data Report'. Link: <http://www.mfe.govt.nz/publications/waste/nat-waste-data-report-may97.pdf> (accessed 22 Jan 2013)

Ministry for the Environment (2009). 'Solid Waste Composition Report'. Link: <http://www.mfe.govt.nz/environmental-reporting/report-cards/waste-composition/2009/waste-composition.pdf> (accessed 22 Jan 2013)

Ministry for the Environment (2010). 'The waste problem'. Ministry for the Environment

Ministry for the Environment (2012). 'Solid Waste Indicator Update'. Link: <http://www.mfe.govt.nz/environmental-reporting/waste/solid-waste/quantity.html> (accessed 22 Jan 2013)

Ministry for the Environment (2013). 'Construction and Demolition Waste'. Link: <http://www.mfe.govt.nz/issues/waste/construction-demo/index.html> (accessed 22 Jan 2013)

Ministry for the Environment (2015). 'Construction and demolition waste: how to manage responsibly'. Link: <http://www.mfe.govt.nz/waste/types-waste/construction-and-demolition-waste>. Access Date: 20/05/2015

Missouri Department of Natural Resources (1998). 'Construction Waste'. Link: <http://dnr.mo.gov/env/swmp/docs/wcs98constructionwaste.pdf>. Access Date: 21/05/2015

Moore, M.; Kazman, R.; Klein, M. & Asundi, J. (2003). 'Quantifying the Value of Architecture Design Decisions: Lessons from the Field'. NASA Goddard Space Flight Center

REFERENCES

- Mora, E. P. (2007). 'Life cycle, sustainability and the transcendent quality of building materials'. *Building and Environment* Vol. 42, p. 1329–1334
- Mortensen Construction (2013). 'Lean Concepts Across Delivery Methods: Mortenson's Lean Journey'. Lean Construction Institute
- Mosier, R. (2013). 'Quantifying Costs and Benefits of Sustainable Projects in the City of Oklahoma City'. Doctor of Philosophy Dissertation. Department of Engineering, University of Oklahoma, Norman, Oklahoma, USA
- Moutavtchi, V.; Stenis, J.; Hogland, W. & Shepeleva, A. (2010). 'Solid waste management by application of the WAMED model'. *Journal of Material Cycles and Waste Management*, Vol. 12, p. 169-183. DOI 10.1007/s10163-009-0285-x
- Moutavtchi, V.; Stenis, J.; Hogland, W.; Shepeleva, A. & Andersson, H. (2008). 'Application of the WAMED model to landfilling'. *Journal of Material Cycles and Waste Management*, Vol. 10, p. 62-70. DOI 10.1007/s10163-007-0186-9
- Moyen, N., et al. (1996). 'Valuing risk and flexibility'. *Resource Policy* Vol. 22, p. 63-74
- Muijs, D. (2011). 'Doing Quantitative Research in Education with SPSS 2nd Edition'. Sage Publishing
- Mukherji, M. (2009). 'Research Methods in Early Childhood'. Unknown Publisher
- Murray, P. E. & Cotgrave, A. J. (2007). 'Sustainability literacy: the future paradigm for construction education?'. *Structural Survey* Vol. 25 No. 1, pp. 7-23
- Myers, D. (2005). 'A review of construction companies' attitudes to sustainability'. *Construction Management and Economics*, Vol. 23, No. 8, p. 781-785

REFERENCES

- Nahmens, I. (2009). 'From Lean to Green Construction: A natural extension'. Construction Research Congress 2009, Seattle, Washington, April 5-7, 2009
- Neale, P.; Thapa, S. & Boyce, C. (2006). 'Preparing A Case Study: A Guide for Designing and Conducting a Case Study for Evaluation Input'. Pathfinder International Tool Series: Monitoring and Evaluation – 1. Pathfinder International
- Nembhart, H., Shi, L. and Aktan, M. (2005). 'A real-options-based analysis for supply chain decisions'. IIE Transactions Vol. 37, p. 945-956
- Nethery, B. (2003). 'The role of Feasibility Studies in mining ventures'. Conference Board of Canada: Structuring More Effective Mining Ventures. Vancouver B.C., AMEC Mining and Metals
- Neufville, R. D. (2003). 'Real Options in Supply Chain Management'. Lecture Notes, MIT
- Neuman, W.L. (1994). 'Social Research Methods'. Allyn and Bacon, Boston
- New Zealand Legislation (2013). 'Waste Minimisation Act 2008'. Ministry of the Environment, Link:
http://www.legislation.govt.nz/act/public/2008/0089/latest/DLM999802.html?search=ts_act_waste_rese&p=1&sr=1 (accessed 22 Jan 2013)
- Newman, P. W. G. (1999). 'Sustainability and cities: extending the metabolism model'. Landscape and Urban Planning Vol. 44, p. 219-226
- New Zealand Brick Distributor (2016). 'Brick Products'. Link:
<http://nzbrickdistributors.co.nz/products/> (accessed 27 May 2016)

REFERENCES

Nguyen, U. N. and Schnitzer, H. (2009). 'Sustainable solutions for solid waste management in Southeast Asian countries'. *Waste Management* Vol. 29, p. 1982–1995

Nielson, C.; Wolfe, C. B. & Conine, D. (2009). 'GREEN BUILDING GUIDE: Design Techniques, Construction Practices & Materials for Affordable Housing'. Rural Community Assistance Corporation, 3120 Freeboard Drive, Suite 201, West Sacramento, California 95691

Nordone, A. J.; White, P. R.; McDougall, F.; Parker, G.; Garmendia, A. and Franke, M. (2009). 'Waste management and minimization'. *Integrated Waste Management, Encyclopedia of Life Support Systems (EOLSS)*

Nouman, M. (2011). 'Research Paradigm and Methodologies: Positivism, Phenomenology, Ontology, Epistemology, Axiology'. Course Material

Novikov, A. M. & Novikov, D. A. (2013). 'Research Methodology: From Philosophy of Science to Research Design'. CRC Press, Taylor & Francis Group

Nurminen J & Pongrácz E (2004). 'Conceptual model of environmental management system (EMS) of reversed information streams'. *Proc. Waste Minimization and Resources Use Optimization Conference*. June 10, 2004, University of Oulu, Finland. Oulu University Press: Oulu. p. 69-81. Editor: Pongrácz, E.

NZIA - New Zealand Institute of Architects (2007). 'Guide to Architect's Charges'. Link: <http://www.saundersarchitects.co.nz/SA/Guide.html>

O'Connor, R. & Swain, B. 'Implementing Lean in construction: Lean tools and techniques – an introduction'. Transform Business Improvement Ltd & Brian Swain Ltd

REFERENCES

Ofori, G. (2000). 'Greening the construction supply chain in Singapore'. *European Journal of Purchasing & Supply Management* Vol. 6, p. 195-206

O'Neil, A. (2011). 'What is a Project Financial Evaluation?'. Link: http://www.ehow.com/facts_5030216_project-financial-evaluation.html#ixzz1FtNNyRJZ <http://www.ehow.com/facts_5030216_project-financial-evaluation.html>. Retrieved March 3, 2011,

Opdenakker, R. (2006). 'Advantages and Disadvantages of Four Interview Techniques in Qualitative Research'. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, 7(4), Art. 11, <http://nbn-resolving.de/urn:nbn:de:0114-fqs0604118pa>

Ortiz, O.; Castells, F. & Sonnemann, G. (2008). 'Sustainability in the construction industry: A review of recent developments based on LCA'. *Construction and Building Materials* Vol. 23, p. 28–39

Osmani, M. (2011). 'Construction Waste'. Book section-Chapter 15, 'Waste: A Handbook for Management'. Editors: Letcher, T. & Vallero, D.

Osmani, M. (2012). 'Construction Waste Minimization in the UK: Current Pressures for Change and Approaches'. *Procedia - Social and Behavioral Sciences* Vol. 40, p. 37 – 40

Osmani, M.; Glass, J. & Price, A.D.F. (2008). 'Architects' perspectives on construction waste reduction by design'. *Waste Management* Vol. 28, p. 1147–1158

Oxford Dictionaries (2014). Link: <http://www.oxforddictionaries.com/definition/english/-logy>

REFERENCES

Paez, O., Salem, S., Solomon, J., & Genaidy, A. (2005). Moving from Lean manufacturing to Lean Construction: Toward a common Sociotechnological Framework. *Human Factors and Ergonomics in Manufacturing* , 15 (2), 233–245.

Palmer (2013). 'The Faux Zero Waste Movement Is Spreading'. *Green Social Thought 62: A Magazine of Synthesis and Regeneration*, Fall 2013

Paparone, C. R. (2010). 'Design and the Prospects of a US Military Renaissance'. *Small Wars Journal*, Small Wars Foundation

PBS (2013). 'San Francisco on Track to Become Zero Waste City'. Link: http://www.pbs.org/newshour/bb/climate-change/jan-june13/recycling_01-25.html

Peng, C-L.; Scorpio, D. E. and Kibert, C. J. (1997). 'Strategies for successful construction and demolition waste recycling operations'. *Construction Management and Economics*, Vol. 15, No. 1, p. 49-58

Persaud, I. (2010). 'Field Study'. Book: 'Encyclopedia of Research Design'. Editor: Salkind, N. J. Sage Publishing

Persson, U. & Olander, S. (2004). 'Methods to Estimate Stakeholder Views of Sustainability for Construction Projects'. *The 21st Conference on Passive and Low Energy Architecture*. Eindhoven, The Netherlands, p. 19 – 22 September 2004

Phillips, P. S.; Tudor, T.; Bird, H. and Bates, M. (2011). 'A critical review of a key Waste Strategy Initiative in England: Zero Waste Places Projects 2008–2009'. *Resources, Conservation and Recycling*, Vol. 55, p. 335–343

Pietersz, G. (2011). 'NPV (net present value)'. Link: <http://moneyterms.co.uk/npv/>

REFERENCES

Poli, R. (2010). Book Chapter: 'Ontology: The Categorical Stance'. Book: 'Theory and Applications of Ontology: Philosophical Perspectives'. Editor: Poli, R. & Seibt, J. Springer Science+Business Media B.V.

Poon, C. S.; Yu, A. T. W. and Jaillon, L. (2004). 'Reducing building waste at construction sites in Hong Kong'. *Construction Management and Economics*, Vol. 22, No. 5, p. 461-470

Poon, C. S.; Yu, A. T. W. and Ng, L. H. (2001). 'On-site sorting of construction and demolition waste in Hong Kong'. *Resources, Conservation and Recycling* Vol. 32, p. 157 – 172

Poon, C. S.; Yu, A. T. W.; Wong, S. W. and Cheung, E. (2004). 'Management of construction waste in public housing projects in Hong Kong'. *Construction Management and Economics*, Vol. 22, No. 7, p. 675-689

PwC (2011). 'Valuing the role of Construction in the New Zealand economy: A report to the Construction Strategy Group'. Link:

<http://www.constructionstrategygroup.org.nz/downloads/PwC%20Report%20-%20Construction%20Sector%20Analysis%20Final%204%20Oct.pdf>

Qureshi, S.; Kazmi, S. J. H. & Breuste, J. H. (2010). 'Ecological disturbances due to high cutback in the green infrastructure of Karachi: Analyses of public perception about associated health problems'. *Urban Forestry & Urban Greening* Vol. 9, p. 187–198

Rahman, I. A.; Nagapan, S. & Sami, A. (2013). 'Initial PLS Model of Construction Waste Factors'. *International Conference on Innovation, Management and Technology Research*, Malaysia, 22 – 23 September, 2013

REFERENCES

Rajasekar, S.; Philominathan, P. & Chinnathambi, V. (2006). 'Research Methodology'. School of Physics, Bharathidasan University, Tiruchirapalli – 620 024, Tamilnadu, India

Rapport F. & Wainwright, P. (2006). Book Section: 'Phenomenology as a paradigm of movement'. Book: 'Qualitative Health Research', Swansea University, Swansea Medical School, Swansea, Wales,

Rawlinsons New Zealand Construction Handbook (2013). 'Quality Commercial and Industrial Construction'. Rawlinsons Publications, A Division of Rawlinsons Limited, Level 4, 135 Broadway, Newmarket, Auckland.

Rebeiz, K. S. & Craft, A. P. (1995). 'Plastic waste management in construction: technological and institutional issues'. Resources, Conservation and Recycling Vol. 15, p. 245-257

References

Revell, A. and Blackburn, R. (2007). 'The Business Case for Sustainability? An Examination of Small Firms in the UK's Construction and Restaurant Sectors'. Business Strategy and the Environment Vol. 16, p. 404–420

Reznick Group (2009). 'Benefit from "Green" Construction Methods'. Reznick Group Renewable Energy Practice

Rijsbermana, M. A. & van de Ven, F. H.M. (2000). 'Different approaches to assessment of design and management of sustainable urban water systems'. Environmental Impact Assessment Review Vol. 20, p. 333–345

Rodrigues, A. and Armada, M. J. R. (2007). 'The valuation of modular projects: A real options approach to the value of splitting'. Global Finance Journal Vol. 18, p. 205-227

REFERENCES

- Rose, S. (1998). 'Valuation of interacting real options in a tollroad infrastructure project'. *The Quarterly Review of Economics and Finance* Vol.58, p. 711-725
- Rubinstein, L. (2012). 'Moving towards Zero Waste & Cost Savings – A Roadmap for Builders & Contractors for Construction & Demolition Projects'. U.S. Environmental Protection Agency
- Samis, M. R., Davis, G. A. and Laughton, D. G. (2007). 'Using stochastic discounted cash flow and real option Monte Carlo simulation to analyse the impacts of contingent taxes on mining projects'. Project Evaluation Conference, Melbourne, Australian Institute of Mining and Metallurgy
- Samis, M., Davis, G. A., Laughton, D. and Poulin, R. (2006). 'Valuing uncertainty asset cash flows when there are no options: A real options approach'. *Resources Policy* Vol. 30, p. 285-298
- Šaparauskas, J. & Turskis, Z. (2006). 'Evaluation of construction sustainability by multiple criteria methods'. *Technological and Economic Development of Economy*, Vol. 12, No. 4, p. 321-326
- Saunders, J. and Wynn, P. (2004). 'Attitudes towards waste minimisation amongst labour only sub-contractors'. *Structural Survey* Vol. 22, No. 3, p. 148-155
- Schilling, J. & Logan, J. (2008). 'Greening the Rust Belt: A Green Infrastructure Model for Right Sizing America's Shrinking Cities'. *Journal of the American Planning Association*, Vol. 74, No. 4, p. 451-466
- Schmitt, T. E. (2014). 'Survey Questionnaire Methodology and Purpose'. Henry Lester and Associates Ltd, La Crosse, Wisconsin, USA

REFERENCES

- Scott, F. (2013). 'Commercialising Waste: Turning Waste Plasterboard in Christchurch into a Valuable Resource'. True North Consulting
- Seabrooke, W.; Yeung, S. C.W.; Ma, F. M.F. & Li Y. (2004). 'Implementing sustainable urban development at the operational level (with special reference to Hong Kong and Guangzhou)'. *Habitat International* Vol. 28, p. 443–466
- Seadon, J. K. (2010). 'Sustainable waste management systems'. *Journal of Cleaner Production*, Vol. 18, p. 1639-1651
- Sealey, B. J.; Phillips, P. S. & Hill G. J. (2001). 'Waste management issues for the UK ready-mixed concrete industry'. *Resources, Conservation and Recycling* 32 p. 321 – 331
- Seattle (2013). 'Resolution Number: 30990'. City of Seattle Legislative Information Service, Office of the City Clerk, Link: <http://clerk.seattle.gov/~scripts/nph-brs.exe?s1=&s3=30990&s2=&s4=&Sect4=AND&l=20&Sect2=THESON&Sect3=PLURON&Sect5=RESNY&Sect6=HITOFF&d=RESF&p=1&u=%2F~public%2Fresny.htm&r=1&f=G> (accessed 04 March 2013)
- Shakantu. M. W. (2005). 'The sustainability of Building Material and Waste Logistics: The case of Cape Town'. PhD Thesis, School of the Built and Natural Environment, Glasgow Caledonian University
- Shehata, M. E. & El-Gohary, K. M. (2012). 'Towards improving construction labor productivity and projects' performance'. *Alexandria Engineering Journal*, Vol. 50, p. 321–33. Link: <http://www.sciencedirect.com/science/article/pii/S1110016812000142>

REFERENCES

- Shekdar, A. V. (2009). 'Sustainable solid waste management: An integrated approach for Asian countries'. *Waste Management* Vol. 29, p. 1438-1448
- Shen, L. Y.; Tam, V. W. Y.; Tam, C. M. & Drew, D. (2004). 'Mapping Approach for Examining Waste Management on Construction Sites'. *Journal of Construction Engineering and Management*, pp. 472-481
- Shen, Q.; Chen, Q.; Tang, B-s.; Yeung, S.; Hu, Y. & Cheung G. (2009). 'A system dynamics model for the sustainable land use planning and development'. *Habitat International* Vol. 33, p. 15–25
- Skoyles, E. R. and Skoyles, J. (1987). 'Waste prevention on site'. Mitchell, London.
- Smith, A.; McNicol, J. & Finlay, G. 'Sustainability in the Residential Built Environment Research Programme 2004-2010'. Landcare Research.
- Smith, J. E. and McCardle, K. F. (1996). 'Valuing Oil Property: integrating option pricing and decision analysis approaches'. *Operations Research* Vol. 46, No. 2, p. 198-217
- Snow, W. (2001). 'Zero Waste: The End of the Age of Waste'. Keynote presentation at the Perth Waste and Recycle Conference 2001, Zero Waste New Zealand Trust
- Snyman, J. and Vorster, K. (2010). 'Towards zero waste: a case study in the City of Tshwane'. *Waste Management & Research*, Vol. 29, p. 512-520
- Sødal, S., Koekebakker, S. and Aadland, R. (2007). 'Market switching in shipping —A real option model applied to the valuation of combination carriers'. *Review of Financial Economics* Vol. 17, No. 21, p. 183-203

REFERENCES

Sjøholt, Odd. 1998. Fra separate miljøstyring til integrert byggstyring – Prosjektrapport 244 – 1998, Norges byggforskningsinstitutt, Norway – translated using Google Translate

Soibelman, L. (1993). “As perdas de materiais na construc_ão de edificac_ões: sua incidência e seu controle” (Material waste in building construction: occurrence and control). MSc dissertation Federal University of Rio Grande do Sul, Porto Alegre, Brazil - in Portuguese.

Solís-Guzmán, J.; Marrero, M.; Montes-Delgado, M. V. and Ramírez-de-Arellano, A. (2009). ‘A Spanish model for quantification and management of construction waste’. Waste Management Vol. 29, p. 2542–2548

Sowards, D. ‘Lean Construction Practices’. Quality Support Services, Inc.

Spatari, S.; Yu, Z. & Montalto, F. A. (2011). ‘Life cycle implications of urban green infrastructure’. Environmental Pollution Vol. 159, p. 2174-2179

Spinler, S., Huchzermeier, A. and Kleindorfer, P. R. (2002). ‘An Options Approach to Enhance Economic Efficiency in a Dyadic Supply Chain’.

Srour, I. M.; Chehab, G. R.; El-Fadel, M. & Tamraz, S. (2013). ‘Pilot-based assessment of the economics of recycling construction demolition waste’. Waste Management & Research, Vol. 31, No. 11, p: 1170 –1179

Statistics New Zealand (2015). ‘Enterprises by industry and business type 2000-14’. Link: <http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE7051#>

REFERENCES

- Steffen, A., et al. (2008). 'Avoiding cost blow-outs and lost time on mining capital projects through effective project stage gating'. Performance Improvement Group, Brisbane
- Storey, J.; Gjerde, M.; Charleson, A. and Pedersen, M. (2003). 'The State of Deconstruction in New Zealand 2003 – Synopsis'. Centre for Building Performance Research, Victoria University
- Symonds Group, Argus, COWI & PRC Bouwcentrum (1999). 'Construction and Demolition Waste Management Practices, and Their Economic Impact'. European Commission
- Tam, C. M. & Tam, V. W. Y. (2006). 'A review on the viable technology for construction waste recycling'. Resources, Conservation and Recycling Vol. 47, p. 209–221
- Tam, C. M.; Tam, V. W. Y. & Tsui, W. S. (2004). 'Green construction assessment for environmental management in the construction industry of Hong Kong'. International Journal of Project Management Vol. 22, p. 563–571
- Tam, V. W. Y. & Tam, C.M. (2006). 'Evaluations of existing waste recycling methods: A Hong Kong study'. Building and Environment Vol. 41, p. 1649–1660
- Tam, V. W. Y. & Tam, C.M. (2008). 'Waste reduction through incentives: a case study'. Building Research & Information Vol. 36, No. 1, p. 37-43
- Tam, V. W. Y. (2008). 'On the effectiveness in implementing a waste-management-plan method in construction'. Waste Management Vol. 28, p. 1072–1080
- Tam, V. W. Y. (2010). 'Rate of Reusable and Recyclable Waste in Construction'. Second International Conference on Sustainable Construction Materials and

REFERENCES

Technologies, June 28-June 30, 2010, Universita Politecnica delle Marche, Ancona, Italy

Tellis, W. (1997). 'Introduction to Case Study'. *The Qualitative Report*, Vol. 3, No. 2. Link: <http://www.nova.edu/ssss/QR/QR3-2/tellis1.html>

Teo, M. M. M. & Loosemore, M. (2001). 'A theory of waste behaviour in the construction industry'. *Construction Management and Economics* Vol. 19, No. 7, p. 741-751

Teo, M. M. M.; Loosemore, M.; Marosszeky, M.; Karim K. and Gardner D. (2000). 'Operatives' attitudes towards waste on construction project'. 16th Annual ARCOM Conference, 6-8 September 2000, Glasgow Caledonian University. Association of Researchers in Construction Management, Vol. 2, p. 509-17. Editor: Akintoye, A.

Thomson, D.; Kaka, A.; Pronk, L. & Alalouch, C. (2014). 'The benefits Quantification Method: A Practical Approach to Engaging Stakeholders in the Judgement of Benefit Realisation'. Heriot Watt University

Till, A. (2013). 'A report on waste in construction and previous research into the economic feasibility of waste minimisation and zero waste'. Unpublished Master's Dissertation. For the Degree of Masters in Engineering Project Management, Engineering Project Management Programme, School of Engineering, AUT.

Tiwana, A., Wang, J., Keil, M. and Ahluwalia, P. (2007). 'The bounded rationality bias in managerial valuation of real options: Theory and evidence from IT projects'. *Decision Sciences* Vol. 38, No. 1, p. 157-181

Todorov, V. & Marinova, D. (2011). 'Modelling sustainability'. *Mathematics and Computers in Simulation* Vol. 81, p. 1397-1408

REFERENCES

- Tommelein, I. D. and Li, A. E. Y. (1999). 'Just-in-time concrete delivery: locating buffers in structural steel supply and construction process'. IGLC-7, p. 109-120
- Tookey, J. E. (1998). 'Concurrent engineering in the aerospace industry: a comparative study of the US and UK aerospace industries'. PhD thesis, University of Bradford, UK, 180- 210
- Topal, E. (2008). 'Evaluation of a mining project using Discounted Cash Flow analysis, Decision Tree analysis, Monte Carlo simulation and Real Options using an example'. International Journal of Mining and Mineral Engineering Vol. 1, No. 1
- Tran, V. D.; Tookey, J. E. Moore, D. & Seadon, J. (2013). 'Waste in New Zealand Construction: Problems, Policy and the Future'. In press
- Treloar, G.; Gupta, H.; Love, P. E.D. and Nguyen, B. (2003). 'An analysis of factors influencing waste minimisation and use of recycled materials for the construction of residential buildings'. Management of Environmental Quality: An International Journal Vol. 14 No. 1, p. 134-145
- Trigeorgis, L. (1996). 'Real Options: Managerial Flexibility and Strategy in Resource Allocation'. MIT Press
- Turner, H. M. & Nye, C. (2007). 'The Campbell Collaboration: Systematic Reviews and Implications for Evidence-Based Practice'. Report, National Center for the Dissemination of Disability Research. Technical Brief No. 16. Link: http://www.ktdrr.org/ktlibrary/articles_pubs/ncddrwork/focus/focus16/Focus16.pdf

REFERENCES

- Tzoulas, K.; Korpela, K.; Venn, S.; Yli-Pelkonen, V.; Kazmierczak, A.; Niemela, J. & James, P. (2007). 'Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review'. *Landscape and Urban Planning*, Vol. 81, p. 167–178
- U.S. Department of the Interior. Bureau of Ocean Energy Management (2011). 'Economic Analysis Methodology for the 5-Year OCS Oil and Gas Leasing Program for 2012-2017'. BOEM OCS Study 2011-050
- Ugwu, O.O.; Kumaraswamy, M.M.; Wong, A. & Ng S.T. (2005). 'Sustainability appraisal in infrastructure projects (SUSAIP): Part 2: A case study in bridge design'. *Automation in Construction* Vol. 15, p. 229 – 238
- UK Government (2015). 'Construction Infographic'. Link: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/229339/construction-sector-infographic.pdf
- UNStats (2015). 'Environment Glossary - Waste'. Link: <http://unstats.un.org/unsd/environmentgl/gesform.asp?getitem=1178>
- Valenzuela, D. & Shrivastava, P. (2003). 'Interview as a Method for Qualitative Research'.
- van der Sloot, H. A.; Comans, R. N. J. & Hjelmar, O. (1996). 'Similarities in the leaching behaviour of trace contaminants from waste, stabilized waste, construction materials and soils'. *The Science of the Total Environment*, Vol. 178, p. 111-126
- Vandermeulen, V.; Verspecht, A.; Vermeire, B.; Van Huylenbroecka, G. & Gellynck, X. (2011). 'The use of economic valuation to create public support for green

REFERENCES

- infrastructure investments in urban areas'. *Landscape and Urban Planning* Vol. 103, p. 198– 206
- Venus, L. Y.H. (2011). 'Green management practices and firm performance: A case of container terminal operations'. *Resources, Conservation and Recycling* Vol. 55, p. 559– 566
- Vidalakis, C., Tookey, J. E. and Sommerville, J. (2011). 'The logistics of construction supply chains: The builders' merchant perspective'. *Engineering, Construction and Architectural Management* Vol. 18, No. 1, p. 66-81
- Voelz, V. A. (2006). 'Hypothesis Testing'. University of California at San Francisco, San Francisco, CA 94143
- Vrijhoef, R. and Koskela, L. (1999). 'Roles of supply chain management in construction'. *IGLC-7*, p. 133-146
- Wahab, A. B. & Lawal, A. F. (2011). 'An evaluation of waste control measures in construction industry in Nigeria'. *African Journal of Environmental Science and Technology*, Vol. 5, No. 3, p. 246-254
- Walls, M. (2004). 'Combining decision analysis and portfolio management to improve project selection in the exploration and production firm'. *Journal of Petroleum Science & Engineering* Vol. 44, p. 55-65
- Wang, J.; Li, S. & Tam, V. W. Y. (2014). 'Critical factors in effective construction waste minimization at the design stage: A Shenzhen case study, China'. *Resources, Conservation and Recycling*, Vol. 82, p. 1– 7

REFERENCES

- Wang, J.; Yuan H.; Kang, X. & Lu, W. (2010). 'Critical success factors for on-site sorting of construction waste: A china study'. *Resources, Conservation and Recycling* Vol. 54, p. 931-936
- Wang, Y. (2009). 'Sustainability in Construction Education'. *Journal of Professional Issues in Engineering Education and Practice* Vol. 135, p. 21-30
- Wangombe, D. K. (2013). 'The Philosophy, Ontology, Epistemology And Methodology Of Research In Corporate Environmental Reporting Behaviour'. The Clute Institute International Academic Conference, Paris, France
- Weathington, B. L., Cunningham, J. L., & Pittenger, D. J. (2010). 'Research Methods for the Behavioral and Social Sciences'. John Wiley & Sons, Hoboken, NJ
- Weber, R. (2004). 'Editor's Comments'. *MIS Quarterly* Vol. 28, No. 1, p. iii-xii
- Weber, T.; Sloan, A. & Wolf, J. (2006). 'Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation'. *Landscape and Urban Planning* Vol. 77, p. 94–110
- White, N. (2012). '2012 Modelling Methodology and Assumptions'. Australian Energy Market Operator
- Whitlock, D. D.; Daigger, G. T. and McCoy, N. (2007). 'The future of sustainable water management: using a value chain analysis to achieve a zero waste society'. Water Environment Federation, WEFTEC®.07
- Wibowo, M. A. (2003). 'The Contribution of the Construction Industry to The Economy of Indonesia: A Systemic Approach'. *Construction Management, Civil Engineering*

REFERENCES

Department, Diponegoro University, Indonesia. Link:
<http://core.ac.uk/download/pdf/11702073.pdf>

Willmott Dixon (2010). 'The Impacts of Construction and the Built Environment'. Briefing Note 33

Wise (2008). 'Green Infrastructure Rising: Best practices in stormwater management'. American Planning Association

Wolf, K. L. 2003 (in press). Ergonomics of the City: Green Infrastructure and Social Benefits. Engineering Green: Proceedings of the 11th National Urban Forest Conference. Washington D.C.: American Forests. Editor: Kollin, C.

Wong, E. O.W. and Yip, R. C.P. (2004). 'Promoting sustainable construction waste management in Hong Kong'. Construction Management and Economics Vol. 22, No. 6, p. 563-566

WRAP (2007). 'Reducing material wastage in construction - Guidance for clients, contractors and sub contractors on how to deliver good practice in materials procurement and usage'. Waste & Resources Action Programme (WRAP), The Scottish Government

WRAP (2009). 'Procurement requirements for reducing waste to landfill: Model procurement wording for construction clients and principal contractors to deliver improved resource efficiency on construction projects'. Waste & Resources Action Programme (WRAP), The Scottish Government

REFERENCES

WRAP (2011). 'Achieving good practice Waste Minimisation and Management: Guidance for construction clients, design teams and contractors'. Waste & Resources Action Programme (WRAP), The Scottish Government

WRAP (2012). 'Actions to reduce waste in construction projects and minor works'. Waste & Resources Action Programme (WRAP), The Scottish Government

WRAP (2013). 'Designing out Waste: A design team guide for buildings'. Waste & Resources Action Programme (WRAP), The Scottish Government

WRAP (2013). 'Designing out Waste: A design team guide for civil engineering'. Waste & Resources Action Programme (WRAP), The Scottish Government

Xie, Y. (2010). 'A Modified method of Mining Assessment under Uncertainty'. 7th International Conference on Innovation and Management, Hong Kong, China

Yahya, K and Boussabaine, A. H. (2006). 'Eco-costing of construction waste'. Management of Environmental Quality: An International Journal Vol. 17, No. 1, p. 6-19

Yang, M. and Blyth, W. (2007). 'Modelling investment risks and uncertainties with real options approach'. International Energy Agency

Ye, G.; Yuan, H.; Shen, L. and Wang, H. (2012). 'Simulating effects of management measures on the improvement of the environmental performance of construction waste management'. Resources, Conservation and Recycling Vol. 62, p. 56–63

Yim, H. L., Lee, S. H., Yoo, S. K. and Kim, J. J. (2011). 'Zero-cost collar option applied to materials procurement contracts to reduce price fluctuation risks in construction'. World Academy of Science, Engineering and Technology Vol. 60, p. 41-46

Yin, R. K. (2004). 'Case Study Research: Design and Methods'. Sage Publishing

REFERENCES

- Yin, R. K. (2011). 'Case Study Research: Design and Methods'. Sage Publishing
- Yip, R. C.P. & Poon, C.S. (2009). 'Cultural shift towards sustainability in the construction industry of Hong Kong'. *Journal of Environmental Management* Vol. 90, p. 3616–3628
- Yu, A. T. W.; Poon, C. S.; Wong, A.; Yip, R. and Jaillon, L. (2013). 'Impact of Construction Waste Disposal Charging Scheme on work practices at construction sites in Hong Kong'. *Waste Management* Vol. 33, p. 138–146
- Yuan, H. & Shen, L. (2011). 'Trend of the research on construction and demolition waste management'. *Waste Management* Vol. 31, p. 670–679
- Yuan, H. (2012). 'Key indicators for assessing the effectiveness of waste management in construction projects'.
- Yuan, H. (2013). 'A model for evaluating the social performance of construction waste management'. *Waste Management* Vol. 32, p. 1218-1228
- Yuan, H. (2013). 'A SWOT analysis of successful construction waste management'. *Journal of Cleaner Production* Vol. 39, p. 1-8
- Yuan, H.; Chini, A. R.; Lu, Y. & Shen, L. (2012). 'A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste'. *Waste Management* Vol. 32, p. 521–531
- Yuan, H.; Shen, L. Y.; Hao, J. J. L. and Lu, W. S. (2011). 'A model for cost–benefit analysis of construction and demolition waste management throughout the waste chain'. *Resources, Conservation and Recycling* Vol. 55, p. 604–612

REFERENCES

Zainal, Z. (2007). 'Case study as a research method'. *Jurnal Kemanusiaan* bil.9, Jun 2007

Zaman, A. U. and Lehmann, S. (2011). 'Challenges and Opportunities in Transforming a City into a "Zero Waste City"'. *Challenges* 2011, Vol. 2, p. 73-93

Zaman, A. U. and Lehmann, S. (2011). 'Urban growth and waste management optimization towards zero waste city'. *City, Culture and Society* Vol. 2, p. 177–187

Zero Waste Alliance (2013). 'Creating a prosperous and inclusive future without waste'.
Link: <http://www.zerowaste.org/>

Zhao, W.; Ren, H. and Rotter, V. S. (2011). 'A system dynamics model for evaluating the alternative of type in construction and demolition waste recycling center – The case of Chongqing, China'. *Resources, Conservation and Recycling* Vol. 55, p. 933–944

Zimina, D. & Pasquire, C. (2012). 'Last Planner System Insights'. Centre for Lean Projects, School of Architecture, Design and the Built Environment, Nottingham Trent University

Zotos, G.; Karagiannidis, A.; Zampetoglou, S.; Malamakis, A.; Antonopoulos, I.-S.; Kontogianni, S. and Tchobanoglous, G. (2009). 'Developing a holistic strategy for integrated waste management within municipal planning: Challenges, policies, solutions and perspectives for Hellenic municipalities in the zero-waste, low-cost direction'. *Waste Management*, Vol. 29, p. 1686–1692

APPENDICES

APPENDIX A – PHASE 1 INTERVIEW QUESTIONS

1. What is your role?
2. Do you have an overall sustainability policy for your organisation?
 - a. If Yes, please elaborate!
 - b. If No, please explain why!
3. What is your definition of waste in construction?
4. What are your main considerations in a project?
5. How does waste management/minimisation fit in?
6. What do you do to manage/minimise C&D waste generated?
7. How much time/effort/cost do you currently have to spend to manage C&D waste?
8. In your opinion, what else can be done at your organisation to minimise C&D waste?
9. If you were to further minimise C&D waste, how much extra time/effort/cost do you think you had to spend?
10. What benefits would you get from managing/minimising C&D waste?
11. From your experience, what are the major challenges in C&D waste minimisation?
12. What do you think about the collaboration in construction?
13. What are your opinions on zero waste for the construction industry?
14. What are constraints that may prevent zero waste in NZ construction?
15. In your opinion, what needs to be done to achieve zero waste in construction?

APPENDIX B – PHASE 1 INTERVIEW RESULTS

Q	Interviewee						
	1	2	3	4	5	6	7
1	Company Director	Company Director	Sustainability Manager	Project Manager	Construction Manager	Sustainability Manager	Category Manager
2	N/A	N/A	Yes	N/A	Yes	Yes	Yes. We actively promote sustainable building practices, including waste minimisation to our customers via our website content and building guides. We have just updated these guides this week. Some good information is available on our website. We have also endorsed the voluntary Code of Practice developed by MAF relating to the importation of timber.
3	N/A	N/A	N/A	N/A	Anything that cannot be integrated into a building. As well as time and money	N/A	Waste is anything that is not re-used, recycled or recovered which is typically sent to landfill or other location for disposal.
4	N/A	We do consulting to communities in relation to waste minimisation and resource recovery	N/A	Time and money	We operate as a Management Contractor so all work onsite is carried out by subcontractors. We supply skips and bins and require subcontractors to put waste into appropriate bins to be recycled	As a contractor, we focus on time and cost	Stores place orders to ensure they are holding enough core lines in stock to meet regular demand from their trade customers and then order other products based on a customer's job specific requirements (i.e. they will order in non-stocked items specifically for each order).
5	Environmental Plan and Sustainability Plan to set KPIs. Capture waste streams in waste management plan	Waste minimisation and resource recovery work hand in hand	N/A	Environmental Plan and Sustainability Plan to set KPIs. Capture waste streams in waste management plan	Our subcontractors purchase the materials so the risk rests with them, as we pay a lump sum for their service	As the Sustainability Manager, I focus on making sure our company personnel and subcontractors meet all required sustainability targets set in contracts, including waste minimisation. This can be hard work, as people do what they've been doing	We encourage our customers to minimise waste through the recommendations in our waste guide. We also encourage customers to use our prefabricated products if possible such as pre-nail Frames & Trusses, Flat pack kitchens, pre-hung doors, etc.
6	BIM and digital = no waste	N/A, as we are not a construction company	N/A	BIM and digital = no waste	We provide skips and bins and require subcontractors to keep site clean and tidy. In case of violation, we issue tidy-up notices to force them to clean up the site	N/A	We have participated in waste audit studies previously (Target Sustainability study in Christchurch, 2008) and have published the results for other stores to benefit from these recommendations.

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7	5% of jobs	N/A	Huge effort to achieve zero waste. Need to affect behaviours of people. But landfill charge is too low	5% of jobs	It takes us a lot of time and effort, as we have to establish preliminary meetings to set agendas with the clients and then with subcontractors before handing over the responsibilities to the subcontractors	Hard to answer. All depends on the job	It is not a time intensive part of my role currently. We have previously spent significant time and effort in researching waste minimisation and developing the guides mentioned above so now it is now a case of continuing to promote and encourage the recommendations to our stores and customers.
8	Culture	Encourage resource recovery centres to work closely with construction companies	Use 80-20 rule in designing out waste	N/A	People being more efficient will help. In demolition jobs, we require at least 80% of waste reduced. As a Management Contractor, we do not generate much waste	Training and Education. Education is a big part. Sometimes I have to run a workshop for both internal and external people to ensure we are on the same page	We have implemented several initiatives above and continue to encourage new initiatives as waste and recycling markets develop. Measuring waste output is difficult at present due to our co-operative structure and lack of quality data available. However, longer term this would provide benefits to us in terms of measuring results.
9	extra 2% to totally remove waste; early engagement	N/A	Roles of architects/designers are important. So require regular collaboration with each other	extra 2% to totally remove waste; early engagement	Not applicable, as we do not generate much waste initially	Hard to answer. All depends on the job	Difficult to answer as it depends as to what level we wanted or needed to minimise waste and this would not be measurable for us as above.
10	N/A	I used to run a not-for-profit company in resource recovery area and we have established a network of resource recovery centres around New Zealand. It was a success	N/A	N/A	Efficiency and cost per dollar return	Image and future work	Please refer to our waste guide which outlines benefits to our customers and these would also apply to us.
11	N/A	Low landfill charges; Lack of markets for recycled materials	Low landfill charges; Lack of understanding in waste industry; No relationship between design and waste industry; No legal requirements for designing out waste; No incentives	Lack of incentives (such as take-back schemes); low landfill charges (increase to \$120 per tonne then we can reduce waste)	Efficiency and return; Educate workmen and clients on requirements and Green Star	Low landfill charges; Lack of incentives; Low skill levels	The availability of viable recycling & recovery markets for major construction waste streams; treated or engineered timber, plasterboard, concrete & masonry, hazardous wastes etc

APPENDIX

12	N/A	N/A	Early days yet	N/A	Between us and our subcontractors: good, as it is mutually beneficial for us to maintain good relationships; Between Client and contractors: need early contractor involvement, as contractors can provide feedback on designs and collaborate more	Can be improved	Unclear on this question but if you are referring to collaboration in the construction industry regarding waste minimisation some work was started in various areas but incentives to minimise waste are very low so viable/economical markets have not developed for some major waste streams e.g. treated timber and plasterboard. Landfill levies and Greenstar projects have definitely encouraged greater efforts and funding for waste minimisation initiatives.
13	Zero waste: not achievable task	Good to have an objective. But will take a long time to achieve it	Good industry goal but have to have pathways to test its applicability. Doable but lots of work to get there	N/A	Absolute zero: not achievable due to human errors and handling and distribution	Ideallistic but worth a try	A very lofty ambition, particularly for the building industry which accounts for approx. half of all waste to landfills! Without strong government support and resulting industry engagement it is highly unlikely to gain major traction towards this goal.
14	Lack of Recovery parks; Lack of Markets; Challenge in getting private developers to care about waste minimisation. On the other hand, big clients have better ethics and will require waste minimisation	As above, lack of markets for recycled materials	N/A	Lack of Recovery parks; Lack of Markets; Challenge in getting private developers to care about waste minimisation. On the other hand, big clients have better ethics and will require waste minimisation	Construction industry is wasteful since materials are cheap but labour is expensive. Poor quality of tradesmanship - low skills and inefficient = waste	Lack of incentives and lack of markets for recycled materials	As above, weak government support and industry engagement.

APPENDIX

15	N/A	Incentives and regulation	N/A	Mandatory requirements and regulation; not enough regulation and incentives	Use and import higher quality products; upskills labour and skills	Upskills workers	<p>a) Strong government support (funding for waste minimisation research, programmes or initiatives, especially for large scale recycling and recovery markets for key waste streams. This could be funded from higher landfill levies) and</p> <p>b) Industry engagement (which will only occur through strong incentives to do so such as higher landfill levies/penalties on specific high volume or high risk waste streams going to landfill). A signal to industry from Government of pending penalties or higher landfill levies unless demonstrable reduction in waste by 20XX would be enough to get relevant industry parties (waste companies/suppliers & merchants/builders) together to form working groups/committees to discuss/promote initiatives to reduce waste. Failing industry engagement I believe penalties/levies only way to move positively towards zero waste goal.</p>
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APPENDIX C – PHASE 2 INTERVIEW QUESTIONS

1. My research found the optimal rate for C&D waste minimisation is between 71% and 78%. What are your opinions on this finding?
2. My study also found design-out-waste also plays an important role in C&D waste minimisation. What are your opinions on this?
3. In your opinion, what can be done to encourage waste minimisation practices in New Zealand construction?
4. Any other comments?

APPENDIX D – PHASE 2 INTERVIEW RESULTS

	1	2	3	4	5	6	7
Question	Company Director	Company Director	Sustainability Manager	Project Manager	Construction Manager	Sustainability Manager	Category Manager
1	It sounds about right. Currently we aim for waste reduction - if we have to - at around that figure. Of course if the contractor can reduce further, it's better because they are likely to get work in next projects. But we don't generally aim for too high	N/A	N/A	N/A	Yes, generally that's the kind of figure we aim for. Naything more than that is not feasible because it costs us more	I think most of our projects aim for a figure in that range. If we can reduce more waste, it's great because we can get more work in the future.	N/A
2	Design stage can reduce waste so it makes sense to consider waste minimisation here. The problem is most clients, except for government clients that we've worked with, they see it as a costly exercise. This is especially true for developers. So in reality design out waste is only done in major government projects	N/A	N/A	N/A	We have our own in house design team and they generally get involved in th design with the architects in our major projects. So we see the value of getting in early with the designers in reducing errors and waste. Contractors need to have a say in a project. But generally this is not always the case so I think we as an industry can do more to improve collaboration	In theory it is great but in reality it is not always the case. New Zealand is much smaller than the UK so I think design out waste is always going to face a challenge in conving people of its value. But definitely deisgn out wast has its values as shown in the case studies in the UK.	N/A
3	Incentives and high penalties for waste dumping	N/A	N/A	N/A	Increase landfill charges	Incentives and high landfill charges	N/A
4	I'd like to get a copy of your study at your convenience	N/A	N/A	N/A	Your study is interesting and can be of value to us	N/A	N/A

APPENDIX E – ETHICS APPROVAL FROM AUT



U T E C
E C R E T A R I A T

8 September 2014

John Tookey

Faculty of Design and Creative Technologies

Dear John

Re Ethics Application: **14/266 Mapping the economic values of a zero waste policy for construction materials in New Zealand.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 29 September 2017.

AUTEC recommends that the researcher offers to conduct interviews off site to protect the privacy of participants and assist in the gathering of responses.

Acting under delegated authority and subject to endorsement by AUTEC at its meeting of 29 September 2014, the Executive Secretary approved the satisfactory resolution of AUTEC's conditions.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 29 September 2014;

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- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>. This report is to be submitted either when the approval expires on 29 September 2014 or on completion of the project.

It is a condition of approval that AUTEK is notified of any adverse events or if the research does not commence. AUTEK approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEK grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,



Kate O'Connor

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Van Dai Tran tran.dai.van@gmail.com

APPENDIX F – CASE STUDY 1 CALCULATIONS

Table 51: Unit Cost Calculations

BASE RATE

Description	Figure	Unit
Charge-out rate per machine (incl. labour)	\$ 120.00	\$/hour
Average Fuel capacity of machine	450	L
Diesel fuel (based on 25L per hour)	3	\$/L

Description	Figure	Unit
Haulage rate	\$ 5.00	\$/km tonne per skip
Haulage capacity	20.00	skip

CALCULATIONS

Description	Symbol	Calculation	Unit
Number of skip hire	Nk	177.00	skips
Skip capacity	Sc	20.00	tonne per skip
Total waste	Ws	3,530.11	tonne
Time to sort 1 skip	Ts	0.50	hr
Distance to travel: from site to processing facility	Dsp	60	km
Distance to travel: from site to landfill	Dsl	60	km
Distance to travel: from processing facility to landfill	Dpl	0	km
Haulage rate	Hl	\$ 5.00	\$/km
Haulage per round trip	Hr	\$ 450.00	\$/trip
Truck capacity	Tc	20	tonne
Number of trips	Nrt	177	trips
unit cost of collecting waste	Ucw	\$ 22.50	\$/tonne
Number of machinery required to sort waste	Nms	15	machines
Charge-out rate per machine (incl. labour)	Cm	\$ 120.00	\$/hour
Total rates	Tcr	1800	\$/hour
Total hours to sort waste	Thw	89	hours
Sort rate	Srw	90%	%
Waste sorted	Sw	3177.099	tonne
unit cost of sorting waste	Usw	\$ 50.42	\$/tonne
Recycling rate	RR	78%	%
Waste recycled	Rw	2753.4858	tonne
Number of machinery required to process waste or recycling	Nmr	15	machines

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Charge-out rate per machine (incl. labour)	Cml	\$	120.00	\$/hour
Time to process waste for recycling	Tpr		1	hour/skip
Total time to process waste for recycling	Ttp		2753.4858	hour
unit cost of recycling waste	Urw	\$	120.00	\$/tonne
unit cost of reusing waste	Urs	\$	120.00	\$/tonne
Total number of machinery used	Tm		192	machines
Average Fuel capacity of machine	Fc		450	L
Diesel fuel (based on 25L per hour)	Df		3	\$/L
unit cost of energy used	Ue	\$	73.43	\$/tonne
GIB weight per sheet	Wg		28.08	kg
Number of GIB sheet per tonne	Ng		36	sheets
Unit cost per GIB sheet	Ug	\$	10.00	\$
GIB cost per tonne	Cg	\$	360.00	\$/tonne

Table 52: Case Study 1 Calculations

UNIT COST			
Landfill charge	\$	150.00	\$/tonne
market price of material i (new)	\$	316.67	\$/tonne
resale price of reused/recycled material i (market rate)	\$	115.00	\$/tonne
unit cost of collecting waste	\$	22.50	\$/tonne
unit cost of sorting waste	\$	50.00	\$/tonne
unit cost of energy	\$	73.43	\$/tonne
unit cost of recycling waste	\$	120.00	\$/tonne
unit cost of reusing waste	\$	120.00	\$/tonne

BENEFIT COMPONENT	LEVEL 1	LEVEL 5	LEVEL 6	LEVEL 7
Intangible benefits	\$300,000.00	\$300,000.00	\$300,000.00	\$300,000.00
Cost saving from reusing materials	\$ -	\$181,538.91	\$277,647.74	\$355,958.64
Cost saving from recycling materials	\$ -	\$181,538.91	\$277,647.74	\$355,958.64
Cost saving from non-disposal of materials	\$ -	\$270,053.42	\$413,022.87	\$529,516.50
Revenue from selling recycled/repurposed materials	\$ -	\$207,040.95	\$316,650.87	\$405,962.65
Total cost saving	\$300,000.00	\$1,140,172.19	\$1,584,969.22	\$1,947,396.43
COST COMPONENT	LEVEL 1	LEVEL 5	LEVEL 6	LEVEL 7
Cost of design out waste + waste strategy	\$ -	\$57,375.00	\$68,850.00	\$75,735.00
Cost of waste strategy	\$	\$90,000.00	\$90,000.00	\$90,000.00

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	90,000.00			
Cost of reusing waste	\$ -	\$ 216,042.73	\$ 330,418.30	\$ 423,613.20
Cost of energy used in repurposing C&D waste	\$ -	\$ 66,100.07	\$ 126,376.79	\$ 194,411.98
Cost of recycling waste	\$ -	\$ 216,042.73	\$ 330,418.30	\$ 423,613.20
Cost of energy used in recycling C&D waste	\$ -	\$ 66,100.07	\$ 126,376.79	\$ 194,411.98
Cost of waste collection + landfilling	\$ 79,427.48	\$ 79,427.48	\$ 79,427.48	\$ 79,427.48
Cost of waste landfill	\$ 529,516.50	\$ 259,463.09	\$ 116,493.63	\$ -
Cost of waste materials	\$ 1,117,879.93	\$ 547,761.17	\$ 245,933.59	\$ -
Total Cost of Waste	\$1,816,823.91	\$1,598,312.34	\$1,514,294.87	\$1,481,212.84
BENEFIT - COST RATIO	17%	71%	105%	131%

APPENDIX G – CASE STUDY 2 CALCULATIONS

Table 53: Case Study 2 Calculations

UNIT COST		
Landfill charge	\$ 150.00	\$/tonne
market price of material i (new)	\$ 316.67	\$/tonne
resale price of reused/recycled material i (market rate)	\$ 115.00	\$/tonne
unit cost of collecting waste	\$ 22.50	\$/tonne
unit cost of sorting waste	\$ 50.00	\$/tonne
unit cost of energy	\$ 73.43	\$/tonne
unit cost of recycling waste	\$ 120.00	\$/tonne
unit cost of reusing waste	\$ 120.00	\$/tonne

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7
Intangible benefits	\$7,000.00	\$7,000.00	\$7,000.00	\$7,000.00	\$7,000.00	\$7,000.00	\$7,000.00
Cost saving from reusing materials	\$ -	\$126.29	\$277.83	\$782.98	\$1,288.13	\$1,793.29	\$2,525.75
Cost saving from recycling materials	\$ -	\$126.29	\$277.83	\$782.98	\$1,288.13	\$1,793.29	\$2,525.75
Cost saving from non-disposal of materials	\$ -	\$88.11	\$193.84	\$546.27	\$898.70	\$1,251.13	\$1,762.15
Revenue from selling recycled/repurposed materials	\$ -	\$29.37	\$64.61	\$182.09	\$299.57	\$417.04	\$587.38
Total cost saving	\$7,000.00	\$7,281.94	\$7,620.28	\$8,748.06	\$9,875.83	\$11,003.61	\$12,638.89
COST COMPONENT	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6	LEVEL 7
Cost of design out waste	\$2,526.43	\$3,031.72	\$3,334.89	\$3,668.38	\$4,035.22	\$4,640.50	\$6,032.65

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Cost of waste strategy	\$1,462.71	\$1,462.71	\$1,462.71	\$1,462.71	\$1,462.71	\$1,462.71	\$1,462.71
Cost of waste collection	\$247.41	\$235.04	\$220.19	\$170.71	\$121.23	\$71.75	0
Cost of waste landfill	\$1,762.15	\$1,674.05	\$1,568.32	\$1,215.89	\$863.46	\$511.02	0
Cost of recycling waste	0	\$17.62	\$38.77	\$109.25	\$179.74	\$312.78	\$528.65
Cost of reusing waste	0	\$3.28	\$7.22	\$20.36	\$33.49	\$58.28	\$98.50
Cost of energy used in repurposing C&D waste	0	\$67.54	\$148.60	\$418.77	\$688.94	\$1,198.89	\$2,026.30
Cost of energy used in recycling C&D waste	0	\$67.54	\$148.60	\$418.77	\$688.94	\$1,198.89	\$2,026.30
Cost of waste materials	\$5,638.89	\$5,356.95	\$5,018.61	\$3,890.84	\$2,763.06	\$1,635.28	\$ -
Total Cost of Waste	\$11,637.59	\$11,945.52	\$12,011.86	\$11,555.90	\$11,133.29	\$11,606.10	\$13,047.20
BENEFIT - COST RATIO	60%	61%	63%	76%	89%	95%	97%